The Story of EARTH SCIENCE

Rocks, Fossils and Minerals

HORACE G. RICHARDS

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THE STORY OF EARTH SCIENCE

THE STORY OF
Earth Science

BY HORACE G. RICHARDS

ILLUSTRATED BY ARTHUR BINK
AND JONATHAN FAIRBANKS

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FIRST EDITION

To those young amateur Earth Scientists who
have brought interesting specimens
to me for identification

Foreword

DURING the past few years there has been a great increase in interest on the part of many people in Earth Science or Geology. This has been partly caused by the increasing emphasis on the need for conservation of natural resources such as petroleum, iron, nickel, etc., and partly because of the stress by schools, scouts, clubs and the like on the outdoors and the consequent growing curiosity on the part of the layman to learn more about the earth on which they live.

Numerous books have appeared discussing various phases of Earth Science such as rocks, minerals, dinosaurs and other fossils. Is this then just another such book? It is hoped that a few differences justify the writing of this work. In the first place, most of the books for the layman in the field of Earth Science have stressed only one, or possibly two, of the branches of the subject. As can be seen by the bibliography at the end of the text, books can be found dealing with fossils, or with rocks and minerals, or with other specific branches of Earth Science. On the other hand, few books for the general reader attempt to give an over-all picture of the entire field of Earth Science. The present book attempts in a very abbreviated form to do this. After a brief discussion of the earth and its various subdivisions, chapters will be found devoted to fossils, rocks, and minerals, the three main branches of Earth Science that should appeal most to the general reader.

It is difficult to separate the field of Geology into distinct subdivisions. To understand fully fossils, one should know

something about the rocks in which they are found. The discussion of rocks and minerals always presents a problem. Should one discuss the rocks first, and then the minerals which make up the rocks? Or, should the minerals be discussed first, since they are the fundamental units? One subject cannot be fully understood without the other. Therefore, it may occasionally be necessary for the reader to refer forward or backward from one chapter to another to understand fully the use of certain terms. For this purpose the index should be useful.

The matter of geologic age also presents a problem. To appreciate the discussion of fossils, one should know their geologic age. However, to thrust the reader into the maze of technical terms of the eras and periods at the very beginning of the chapter on fossils might be too discouraging. Therefore, the few age terms used in the early parts of the book are placed in parentheses, and can be omitted by the reader if he so desires. The use of the pictorial timetable in the frontispiece should be helpful in this connection.

The writer has tried to make this book slightly different in still another respect. There seem to be numerous books for the very young reader on the market, and of course, there is an extensive list of text books and similar works for the advanced student. On the other hand, there seems to be a scarcity of books for the slightly advanced reader who, while not being able to use the advanced text books, is not satisfied with the numerous excellent works for the beginner which are now available. In other words, he wants some technical information, but does not want to be completely engulfed by an overabundance of long technical words.

The writer is indebted to numerous individuals for help in the preparation of this book. The section on fossils has been checked by Dr. B. F. Howell, of Princeton University, while those on rocks and minerals have been read by Dr. E. T.

Wherry and Mr. S. F. Thoumsin, both of the University of Pennsylvania. The manuscript has also benefited by the careful reading and criticism of Mr. Theodore M. Hesser, Jr., of the Delaware Township High School of Camden County, New Jersey, and Mr. William Overlease, of the Department of Education at the Academy of Natural Sciences of Philadelphia, both of whom have had considerable experience with the education of young people in the fields of Natural History and Earth Science. While the help of these various individuals has been greatly appreciated, they should not in any way be held responsible for errors or ambiguities in the text. Finally, the author wishes to express his appreciation for the cooperation on the part of the two artists, Arthur R. Bink, and Jonathan Fairbanks, who have worked closely with him in the preparation of the various illustrations.

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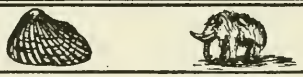
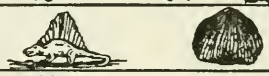
THE STORY OF EARTH SCIENCE

GEOLOGICAL TIME TABLE

ERA		EPOCH AND YEARS AGO (TO BEGINNING OF PERIOD)	TYPICAL ILLUSTRATIONS OF THE PERIOD	POPULAR NAME
CENOZOIC	"QUATERNARY"	PLEISTOCENE 1,000,000		ICE AGE
	"TERTIARY"	PLIOCENE 12,000,000 MIOCENE 28,000,000 OLIGOCENE 40,000,000 EOCENE 60,000,000 PALEOCENE 70,000,000		AGE OF MAMMALS
MESOZOIC		CRETACEOUS 130,000,000		AGE OF REPTILES
		JURASSIC 155,000,000		
		TRIASSIC 185,000,000		
PALEOZOIC		PERMIAN 210,000,000		AGE OF COAL
		PENNSYLVANIAN 250,000,000		
		MISSISSIPPIAN 265,000,000		
		DEVONIAN 320,000,000		AGE OF FISHES
		SILURIAN 360,000,000		
		ORDOVICIAN 440,000,000		AGE OF INVERTEBRATES
		CAMBRIAN 520,000,000		
		PRE - CAMBRIAN 2,000,000,000+		

Introduction

AS FAR BACK as the earliest recorded history, there have been students of Earth Science. It is true that the term Earth Science was not invented until quite recently, but the natural philosophers of ancient Greece and Rome concerned themselves with the mysteries of the earth, its shape, origin and dynamic processes such as earthquakes, volcanoes, weathering and the like. We may not agree with all the interpretations of the ancients, but we cannot help but marvel at their attempts to interpret complicated scientific phenomena with so little information at their disposal.

The importance of certain minerals and metals was keenly understood by all primitive people, if not from a scientific point of view, at least from a standpoint of usefulness. The earliest known geological map is that of a gold mine near Thebes in ancient Egypt and is said to date from the nineteenth Dynasty (1350–1205 B.C.).

Fossils were known to the ancients, and while in many cases their interpretation was entirely wrong, a few of the scholars actually understood their significance. For example, the Greek historian Herodotus observed fossil sea shells in the deserts of Libya and Egypt and correctly deduced that the Mediterranean Sea had covered the region at some earlier period.

For a long time the earth was supposed to be only a few thousand years old—as old as the history that had been written by men. Until recently, most people were little interested in fossils and explained them as "freaks of nature," or "devices of the devil." Early in the nineteenth century, as layers of

rock were carefully studied, men realized the great age of the rocks and the fossils in them, and understood fossils to be true relics of prehistoric life. The earth scientist today has two major problems. From his place on the surface of the earth, he must find where the many types of rocks and natural resources occur beneath the surface, out of his reach by ordinary means. Secondly, he must piece together the long and complex history of rock forming, mountain building, flooding and draining, depositing and eroding; slow processes which have made the earth what it is today, over a period of several billion years. Every bit of information about the earth, its past and present, may help us solve the riddle of the rocks, both satisfying our scientific curiosity and the economic necessity of locating valuable mineral resources.

Only during the present century has the practical importance of Earth Science been brought home to the average American. During World War II there were shortages of necessary materials such as oil, steel, and nickel. The geologist was then not only a "rock collector," who enjoyed outdoor field trips and cherished beautiful and unusual rocks or minerals, but an economically important person who was contributing to the welfare of the country by looking for new deposits of iron, manganese, copper and other minerals. The paleontologist, or student of fossils, in addition to collecting old bones and shells which told him of the fascinating variety and development of life in the distant past, also became important in the ever increasing search for new oil supplies. His fossils, once curiosities for a few, now became important to many as indications of where oil might be found.

For all practical purposes, the term Earth Science is identical with that of Geology. Strictly speaking, Earth Science might be a little broader than Geology and take in such studies as Astronomy, Meteorology, and Archeology.

If you were to become a geologist, you might specialize

in one of the many branches of Geology, a few of which are mentioned here:

Mineralogy: The study of minerals.
Petrology: The detailed study of rocks.
Paleontology: The study of fossils.
Geomorphology: The study of how the present land surface was formed and shaped.
Stratigraphy: The study of the layered rocks; their ages and relation to each other.
Economic Geology: The study of ores, mines, and natural resources.

While our book will concentrate on two branches of Geology —Mineralogy and Paleontology—it will be necessary for us to include other phases of the subject. To begin with, we will have to learn something about the earth, its different regions, as well as a brief timetable of the principal events in its very long and complicated history. Let us begin with the subdivision of the earth into its main parts.

1

The Three Major Divisions of the Earth

THE EARTH can readily be divided into three main parts, the atmosphere, hydrosphere and lithosphere. While our book will be largely concerned with the third division, it might be as well to say something about each one of these subdivisions.

THE ATMOSPHERE

The atmosphere, or air, plays an important part in the changing and wearing away of rocks on the earth's surface. It is a mixture of many gases, mainly nitrogen (78 per cent) and oxygen (21 per cent), extending upward from the earth about 500 miles. At this altitude it is very thin; most of the air is concentrated within a few miles from the ground.

The atmosphere can be divided into several zones or layers, each with certain physical properties and chemical composition which are characteristic. The lowest zone is the *troposphere,* so called because of the convection currents or overturning of the air. (Tropo means turning.) The height of the troposphere varies with latitude, season and barometric pressure, but may be said to average about 6 or 7 miles. Dust and water vapor are generally confined to the lower portions of the troposphere. The amount of oxygen also decreases upward as does the temperature.

The *stratosphere* lies above the troposphere. This is a region of thin, dry air. Between elevations of 15 and 30 miles there is a zone in which ozone is present in greater quantities than nearer the earth. It is very fortunate for us that this zone exists where it does, for the ozone, which is similar to oxygen except that the atoms are arranged differently (linked in groups of three instead of two) intercepts a large portion of the ultraviolet rays that come toward the earth from outer space. It is also fortunate for us that this ozone layer is relatively constant in its content, for if it increased, it would adsorb so many of these ultraviolet rays that life on earth would perish because of the lack of energy and vitamins contained in these rays. On the other hand, if the ozone were decreased, so many ultraviolet rays would reach the earth that most life would be "burned up" after a few minutes' exposure to the sun's rays.

The zone of atmosphere which most influences the rocks and minerals of the earth is, of course, the troposphere. The chemicals carried by the air act on the rocks causing them to break down slowly or decompose. Furthermore, the movement of the troposphere, in other words the wind, causes sand and dust to be transported many miles, while the scouring action of the particles so transported may cause a great amount of weathering.

THE HYDROSPHERE

This division of the earth includes the oceans, seas, lakes and rivers as well as the underground water that is present in many subsurface rock formations. The ocean constitutes the greatest part of the hydrosphere and in fact covers approximately 70 per cent of the earth's surface. The greatest known depth lies in the Pacific Ocean off the Philippine Islands in the so-called Mariana trough where a depth of more than 6 miles has been recorded. The average depth of the

ocean is about 2½ miles. The shallow portions of oceans generally lie close to the land, although in a few cases, such as off the Philippines and certain of the Caribbean Islands, the ocean floor drops to tremendous depths only a few miles from the shore line.

In most cases, the land slopes gently from the shoreline out to sea. This region covered by water of less than 100 fathoms (600 feet) is called the *continental shelf*. Its width varies from less than 10 miles off California to 100 miles or more off the northeastern Atlantic Coast. Somewhere near the 100 fathoms contour, the sea floor generally greatly increases its slope and plunges to great depths. This region of greatly increased slope is called the *continental slope* and may extend as much as 250 miles to a depth of some 6,000 feet where it merges with the abyssal zone, or the deep-sea floor.

Shore lines are constantly changing. Many people have witnessed drastic changes within their own lifetime, and even greater changes are known to have taken place during historic time. If one were to base his observations on a single locality, for example, Cape May, New Jersey, the conclusion would easily be reached that the land was sinking (or the sea rising) at an alarming rate. A study of old maps shows the loss of several miles of land since the early settlement of the region, some 250 years ago. The same thing would be true from studies at Cape Hatteras, North Carolina, or many places along the North Sea in Europe. On the other hand, if one were to confine his observations to Cape Lookout, North Carolina, Wildwood, New Jersey, or the eastern end of the Mediterranean, he could not help but come to the conclusion that the land was rising (or sea level falling).

The earth scientist must examine evidence from many places before reaching any general conclusions. As a result of studies

along many shore lines, in various parts of the world, the following general conclusions have been reached.

1. In some places the land is slowly sinking. For example the Deep Delta of the Mississippi River south of New Orleans is sinking largely because of the great weight of the mud and silt being transported down the river. The land level has sunk at least 28 feet in the past 2,000 years.

2. In other places the land is rising. In some cases this is due to movements deep within the earth, as along the coast of California or in eastern Cuba; in other places the rise is caused by an adjustment or rebound following a sinking of the land caused by the weight of the great glaciers. This type of rise is now taking place in the Great Lakes region, Hudson Bay and Northeastern Canada as well as in most parts of Scandinavia.

3. There is also a slow, almost unnoticeable rise of sea level caused by the water pouring into the sea from melting glaciers. The climate is slowly becoming warmer, causing many of the glaciers of the world to recede and to pour their melt-water into the sea.

4. Numerous other natural causes will bring about significant changes in shore line. The frequency of storms and the direction of the prevailing shore currents are responsible for many of the striking changes that have taken place during recent years along the coast of the Atlantic states from New Jersey to Florida. Some of these factors can be counteracted or emphasized by man, if he so desires. For example, the stone jetty built at the entrance of Cape May Harbor in New Jersey disrupted the normal flow of shore currents, causing a great increase in the amount of sand added to the region north of the jetty (Wildwood) and a consequent lack of material added south of the jetty (Cape May). At the same time, land continued to be carried away by the shore cur-

rents causing a total net increase to the real-estate acreage of Wildwood and an alarming loss of valuable land in Cape May. (It should be stated that it was not the purpose of this jetty either to add or to subtract land; it was built as a wartime emergency measure during World War I to create a deep harbor for the Coast Guard.)

Deltas caused by rivers can bring about a major change in the contour of the shore line. This is taking place today in the deltas of the Mississippi, Colorado and many other rivers of the world. One of the most striking changes in shore line which has come to the attention of the writer is that near the biblical town of Tarsus in Turkey, along the eastern shore of the Mediterranean. Excavations for the Roman town, of perhaps 2,000 years ago, revealed a sea wall, obviously built to keep back the waters of the Mediterranean. But now, the sea is 30 miles distant, having retreated that much owing to the sediments deposited by rivers flowing into the sea from the nearby hills.

If changes of such magnitude can take place within recorded historic time, what about the changes that have taken place over a period of millions of years? We can climb almost any mountains such as the Rockies or Appalachians and there at the top find fossil sea shells or other evidences that at one time the region had been covered by the ocean.

Restricting our observations to the more recent episodes of geological time, we frequently find evidence that much of the land just above the present shore line was recently beneath the sea. By "recent" we are speaking in a geological language and mean "within the past few million years." Going out to sea from the present beach, we frequently find evidence that the continental shelf was once and not so long ago, geologically speaking, dry land, and is really nothing more than the continuation of the emerged "coastal plain."

The importance of the continental shelf has recently been brought to the attention of everyone by the arguments about the so-called "tideland" oil, which really has nothing to do with the tidal zone, but actually comes from beneath the shallow water of the continental shelf.

Perhaps in our discussion of the hydrosphere, we have concentrated too much on the ocean and too little on the other waters of our world. However, as we study the history of the earth and its fossils, we will find that ancient oceans played a very important role, and only by understanding events that are taking place in our oceans today can we fully interpret the rocks, fossils and minerals which played a part in the geological history of the world.

However, not all changes are caused by the sea. Water, whether it be in streams, rivers or underground, has a tendency to wear away the rocks and consequently to change the scenery. Such beautiful spots as Natural Bridge, Virginia, Mammoth Cave, Kentucky, Rainbow Bridge and countless other wonders of nature have achieved their present forms by the erosive action of water.

THE LITHOSPHERE

This is the solid portion of the earth, and includes not only the land which is above the sea, but also that which lies beneath the sea, including that below the greatest depths of the ocean. It is, of course, this zone that we will be most concerned with in this book, for it is this zone that contains practically all of our rocks, fossils and minerals that we will describe later in this book.

We might anticipate our discussion of rocks of the lithosphere by stating that rocks can be grouped into three main divisions, and since it will be necessary to use these three names

frequently throughout the book, we might do well to define them briefly now.

Sedimentary rocks are those deposited as sediments, usually from previously formed rocks. This group includes sand, sandstone, shale and limestone.

Igneous rocks are those formed by the hardening of hot liquid material that has risen from deep within the earth. This group includes granite, basalt, lava and ash.

Metamorphic rocks are those that have been derived from the recrystallization of other rocks usually under great heat and pressure. Examples include quartzite (from sandstone), marble (from limestone) and slate (from shale).

While practically all the specimens described in this book are to be found at or near the surface of the earth, some of the rocks and minerals were originally formed deep within the earth and reached their present location as a result of volcanoes or other upheavals. Speculation about the conditions deep within the earth will make these processes clearer.

The lowest point on the surface of the earth is the Dead Sea in Palestine, the surface of which is 1,268 feet below normal sea level. The deepest mine which has actually been penetrated by man is in South Africa, and extends to a depth of about 12,000 feet. Oil wells are constantly being drilled deeper and deeper and at the present writing, the deepest one is in Louisiana which extends to a depth of more than 26,000 feet, or almost four miles.

Deep as these holes may appear, they really only scratch the surface of the earth. If the earth were reduced to the size of an orange, these variations would be so small that they would be unnoticed without microscopic measurement. While we have obtained much information from deep mines and wells, the rest of our knowledge of the interior of the earth must come from indirect observations or merely from speculation.

A study of deep wells tells us that the temperature increases with depth. Near the surface the increase is known to average about 1 degree C. per 100 feet (= 1 degree F. per 60 feet). While it is not known whether this increase is constant, it is generally estimated that the temperature at the center of the earth ranges between 2,000 and 4,000 degrees C. (= 3,600 and 7,200 degrees F.).

How can we determine the kind of rock that exists below our deepest wells? The answer to this question comes from a careful study of earthquakes. Earthquakes originate at a point usually a few miles beneath the earth's surface. From this point, waves of several kinds travel in all directions through and around the earth.

A study of these earthquake waves is useful in telling something about the rocks of the earth through which they pass. It has been shown that the earthquake waves travel at different speeds through different kinds of rocks and furthermore that the different kinds of rocks occur in definite layers beneath the earth's surface. Equally important information has been obtained by man-made earthquake waves such as those set off by the geophysicists in mapping the underground formations in a search for oil and by similar geophysical observations made both on land and beneath the floor of the sea.

Without going into the complicated calculations involved in such experiments, let us summarize briefly some of the generally accepted interpretations of the structure of the interior of the earth.

The immediate surface of the earth is made up of a relatively thin layer of sedimentary rocks. This layer varies in thickness from nothing in some places to more than 10 miles. While this variation may seem great, it is very small in relation to the size of the earth. Beneath this sedimentary layer, there is a zone of moderately dense rocks known as granite. In some places, where the sedimentary layer is absent, the

granite occurs on the surface of the earth, but generally it is covered by a mantle of sediments. The thickness of this layer varies, but is believed to average about 10 miles. It is, however, very thin or absent beneath the various oceans. Beneath the granite layer is an even denser layer made up mainly of rock known as basalt. This extends to an approximate depth of 37 miles. Beneath the basaltic layers are several bands of even denser, harder rock that constitute the mantle. This layer is apparently made up largely of minerals of basic rocks and metallic iron. The inner core is probably composed of metallic iron or iron and nickel, part of which may be liquid.

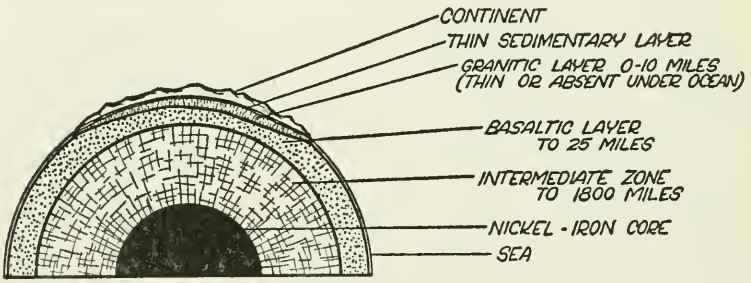


Fig. 1. Cross section of the Earth showing the various layers (scale exaggerated near the surface).

While it is true that much of our knowledge, or rather our inferences, concerning the interior of the earth has come from a study of earthquake waves (Seismology), we have also been able to deduce certain information from the science of Astronomy, especially by a study of meteorites which have fallen on the earth from outer space and which are thought to be comparable to material occurring deep within the earth.

2

Geological History

THE HISTORY of the earth can be divided into two very distinct phases. The earlier of the two concerns the origin of the earth itself and is closely related to the even greater problem of the origin of the solar system and the universe. This phase is closely related to the science of Astronomy and cannot be solved by ordinary geological methods. In a sense, it falls into the field of speculation. The other phase, the "recoverable" history concerns the events that have taken place after the final solidification of the earth and the beginning of such processes as sedimentation and weathering. This can be at least partly interpreted by a study of the rocks, fossils and minerals that comprise the outer layers of the earth.

While our book will largely be concerned with the second phase, let us briefly speculate concerning the beginnings of our planet. The mystery of the origin of the earth has intrigued philosophers and scientists for centuries, and even today no one knows the answer to the riddle. An hypothesis long held by scientists proposed that a large rotating disc-like gaseous cloud, called a nebula, extended far beyond our solar system, and slowly spun. As the gas cooled, the nebula shrank in size and increased its speed. Eventually, portions of the nebula evolved into the sun. This is called the Nebular Hypothesis, and was first proposed by the philosopher Kant in 1755 and was expanded by the astronomer Laplace in 1796.

Another hypothesis suggested that a star passed near the

sun causing great tidal bulges to appear on the sun because of the gravitational pull of the star. A series of "bolts" was thus torn away from the sun. These formed planetesimals which eventually gathered together as the various planets. Secondary "bolts" formed the moons which revolve around the earth and other planets while meteors are regarded as planetesimals which are still being attracted to the earth. This is the Planetesimal Hypothesis of Moulton and Chamberlain first proposed in 1896. Still other theories, or hypotheses, have been advanced by geologists and astronomers, but thus far not one has been entirely accepted by all scientists. There are apparent insurmountable objections to each. While there is still no agreement, there seems to be a tendency at the present time to return to the Nebular Hypothesis of Laplace with many modifications and extensions.

Even if we could solve the riddle of the origin of the earth and the solar system, we would be faced with the even more difficult problem of the origin of the sun and the rest of the stars and galaxies of the universe. However, these problems are beyond the scope of the earth scientist and we will be happy to leave them to the investigation and imagination of the astronomer.

Before coming to the second phase of geological history—that phase which we will try to interpret from the rocks making up the surface of the earth, it is important to examine the tool which will be most useful for us in this study. This tool is the fossil.

WHAT IS A FOSSIL?

The word fossil is in rather general use but not everyone knows exactly what a fossil is — and is not. A fossil may be defined as "the remains or trace of an animal or plant that lived in a period earlier than the present." The *remains* might

be a shell, bone, tooth, leaf, or any other actual part of the animal or plant. A *trace* on the other hand might be a footprint, trail, or burrow. The organism itself may not be preserved but the trace proves the existence of the actual living animal or plant. What do we mean by the present? You may see the skeleton of a cat that was run over yesterday. Is that a fossil? Yesterday was before the present, but it would be very inappropriate to call that skeleton a fossil. How old must a specimen be to be called a fossil? What is the difference between an "old shell" and a "young fossil"? There are no answers that are accepted by everyone, and one must be arbitrary in establishing a line between fossil and recent specimens. Many geologists have agreed to draw this line at the time of the retreat of the last glaciation. Thus, the remains or trace of an animal or plant that lived before the retreat of the glaciers would be a fossil; one that lived after the retreat would not.

Exactly when did the glaciers begin to retreat? At different times in different places, but we can make the general statement that these glaciers began to withdraw from North America about 12,000 years ago. Admittedly, this is a very arbitrary distinction, but it is the best that we can do under the circumstances.

There are several popular misconceptions about fossils. One is that a specimen must be *petrified* or *altered* to be called a fossil. This is not the case. It is true that many fossils are petrified or altered, but, as will be seen later, many fossils are entirely unaltered and cannot be told from specimens that died only a few weeks or years ago.

Another misconception is that all fossils are of extinct species. This also is untrue. Many fossils, such as dinosaurs and trilobites, are extinct and have been so for millions of years. But many other plants or animals have remained unchanged for millions of years. Their remains are equally fos-

sils even though their identical descendants are living today. Some fossil shells are exactly the same as those living in present-day oceans, yet they fulfill all the requirements of the definition, and thus are termed fossils.

How then can you tell whether a shell is a fossil or not? The answer is that sometimes you cannot, unless you know exactly where it came from, and even then sometimes you are not sure.

Two clam shells can be placed side by side on the table; one was obtained from the ocean or bay and is obviously "recent"; the other came from a pit many miles inland from the ocean. How can one tell which is the fossil? If the specimen from the pit was an extinct species, it would be fairly obvious that it was a fossil. On the other hand, if the same species had persisted from Miocene time, 19,000,000 years ago, to the present, it would be impossible to tell which was the fossil provided both were unaltered, unless you knew where they came from. Marine shells dug up far from the present shore line are most probably fossils. This is not an absolutely foolproof test for there have been rather drastic changes in the shore line within relatively few years. Furthermore, shell beds can be man-made, for example the great Indian shell heaps at Damariscotta, Maine, and along the Gulf of Mexico in Florida, Alabama, and elsewhere. However, these modern shell beds can generally be recognized from careful field evidence.

Most shells washed onto an ocean beach are modern, but not necessarily all. If the beach is near a fossil deposit, shells washed from the fossil beds are carried onto the beach and mixed with recent specimens; or the fossils may be carried from deposits beneath the sea. For example, the beaches of Chesapeake Bay in Calvert County, Maryland, contain a mixture of fossil shells washed from the Calvert Cliffs and those living in the waters of Chesapeake Bay. In the case of the

extinct species, there is no problem for the trained paleontologist to tell the fossil from the recent specimens. In the case of those species that have persisted unchanged for millions of years, there is no sure way of separating the fossils from the non-fossils.

We have given only one example of a "mixed fauna." We could give many others, for example, along the Pacific Ocean north of San Diego where there is a mixture of fossil and recent mollusca, the former having washed from the extensive bluffs at Pacific Beach. Nor need our examples be limited to shells. It is sometimes equally difficult to tell whether bone is fossil or recent. The bones and teeth of numerous extinct animals have been washed onto the beaches of South Carolina, especially at Edisto Island, and it is thought that these were transported by the waves from a submarine deposit of the Ice Age.

Fossils can be classified by their method of preservation, the two main divisions being unaltered and altered.

UNALTERED FOSSILS

Although these are less frequent than the altered variety, they are by no means rare. Let us mention a few examples of unaltered fossils.

The preservation of soft parts is extremely rare and only known from a few places, almost none from North America. The examples most familiar are the frozen mammoths found in the tundras of northeastern Siberia. These ancient mammals probably were trapped in bogs and then frozen. They are exposed today in places where the bogs have melted. People have asked, "Is the flesh good to eat?" The answer is, theoretically, "It could be if the flesh were frozen quickly enough." However, it is believed that at least most of these animals underwent considerable decomposition before the

"deep freeze." Consequently, the meat was partly rotten before it was frozen, and so is not edible today.

Other examples of fossil soft parts include the rhinoceroses found in the oil- and brine-soaked sands of Galicia in eastern Poland (now a part of the Soviet Union). Some of this flesh was well enough preserved to permit microscopic studies of the cell structure.

Neither of these examples are very ancient as fossils go, however, they must date back some 10,000 years or more, which is certainly a long time for flesh to be preserved.

Fossil mummies are very much like those cited above, except that they have been completely desiccated. A few such fossils have been found in caves in southwestern United States and recently a mummified baby mammoth was uncovered in frozen ground near Fairbanks, Alaska. The Egyptian mummies were, of course, partly preserved by the skill of the ancient Egyptians, but their preservation was aided by the dry desert climate of the region. Obviously these mummies cannot be regarded as fossils because of their relatively recent age.

Amber is fossil resin of plants. Sometimes insects or small animals were trapped in this sticky substance and are thus preserved intact. While amber has been found in many geological formations, the best known specimens come from the Baltic Coast of Germany and from Zanzibar in East Africa. The insects preserved in this amber date from the Tertiary (Oligocene) and thus are some 40 million years old.

Unaltered shells have already been discussed. While it is generally true that unaltered shells date from younger geological periods (Mesozoic or Cenozoic), perfect examples of unaltered fossil shells are known from formations as early as the Cambrian—500,000,000 years old. Examples of unaltered Cambrian braciopods are known from British Columbia, Wisconsin and near Leningrad, Russia.

Unaltered bones also have been mentioned. Like the shells, they generally, but not always, date from the more recent geological periods.

Unaltered wood is the final example in this group. Under normal circumstances, wood will decay relatively rapidly. However, if wood is buried in peat, it may be preserved more or less indefinitely. This will explain the occurrence of fresh-looking logs uncovered from peat bogs in various parts of the world.

In Cape May County, New Jersey, "fossil" cedar logs were once "mined" in Great Cedar Swamp and were used for shingles. In fact, there is a tradition that the roof of Independence Hall in Philadelphia was made of shingles dug from this swamp. While no tests have been made to determine the exact age of this wood, it is certainly of considerable antiquity and must date back at least 5,000 years.

Excavations made a few years ago in Washington, D. C., and in Philadelphia revealed cypress logs that were so fresh that there was considerable argument as to whether they were fossils or not. Both have now been dated to the Pleistocene, going back some 25 to 100 thousand years.

Slightly altered wood is called lignite, which in turn can be altered to coal. While lignite should be classed as an altered rather than unaltered fossil, some lignitic deposits do contain specimens of very fresh unaltered wood. Examples are known from the fossil beds (Cretaceous) at Cliffwood, New Jersey (along Raritan Bay), and along the Chesapeake and Delaware Canal near Bethel, Maryland.

ALTERED FOSSILS

Petrifaction covers fossils parts of which have been unaltered and part altered. The original shell or bone is preserved in these specimens, but has been augmented by the addition

of some substance such as silica or calcium carbonate that has been transported by the underground water. These fossils are greatly increased in weight and are called *permineralizations* or *petrifactions*. This type of preservation is especially characteristic of bone.

Replacement occurs when the original substance of the shell or bone has been dissolved away by the action of the ground water and has been completely replaced by another substance. This replacement can be so gradual that the detailed microscopic structure may still be visible in the fossil. This is especially true when the replacing material is lime or calcite. On the other hand, some petrified wood may be completely replaced by silica which under some circumstances preserves the cellular structure of the original wood. Still another replacing material is pyrite. Certain Jurassic shells, from localities in Bavaria, Germany, have been replaced in this way and make beautiful specimens that are much sought after because of their golden appearance.

Under certain circumstances, when plants or animals decay, they leave behind them a thin film of carbon that retains the original form and structure. These are known as carbonizations. Probably the most familiar examples are some of the fossil fern leaves and other plants found in coal deposits. Other classic examples of this kind of preservation are the beautifully preserved jellyfish, worms, trilobites and other fossils found in the shale near Field, British Columbia, (Cambrian) and certain marine reptiles found in the rocks, (Jurassic) near Holzmaden, Württemberg, Germany. In all these fossils a thin film of carbon outlines the form of the organism frequently revealing the detailed structure of the soft parts.

MOLDS, CASTS AND TRACES

If the remains of the animals disintegrate or dissolve, a complete impression is often left behind in the rock. This is

called a mold. If the mold is filled with some mineral substance such as calcite, pyrite or chalcedony, this filling is called a natural cast or pseudomorph. Casts can also be made artificially by the paleontologist by filling the mold with some substance such as wax, clay, or latex. In this way, many structural details not seen on the mold can be studied.

In the case of traces the actual remains of the animal or plant are not preserved, but some proof or trace of the existence of the organism can be found in the rocks. This trace can be in the form of footprints, trails, burrows (such as of a worm or boring mollusk), excrement (coprolites), or highly polished stones that have been swallowed by reptiles as an aid to grinding their food (gastroliths).

PSEUDOFOSSILS

Pseudofossils are inorganic specimens which closely resemble fossils and which often are confused with them. One of the most common pseudofossils is a dendrite, which is a natural mineral growth of manganese oxide produced in underground water. Their growth pattern resembles that of a fossil fern, and very frequently they are collected as such by the inex-

FIG. 2. A dendrite, a manganese mineral resembling a fern. This is often mistaken for a fossil, and is consequently known as a pseudofossil.

perienced paleontologist. Furthermore, on many occasions, pebbles, concretions, nodules and even buried roots have the general appearance of fossils and may easily be confused with true fossils by the collector.

SPECIMENS NOT OLD ENOUGH TO BE FOSSILS

Paleontologists frequently receive telephone calls or letters regarding the discovery of some large fossil animal found in excavations for roads, sewers, houses, or the like. In fact, many important discoveries have been brought to light by the helpful cooperation of the amateur or of the general public. Unfortunately, however, many of these "discoveries" turn out to have less than scientific importance. The author wishes that he had kept a record of the many times that he has rushed out to excavations in response to such a telephone call, hoping to find a dinosaur or a mastodon, only to see the remains of a horse, cow, or other domestic animal of no geological age or importance. For some reason horse teeth seem to fascinate the uninitiated. Probably people do not realize the size of a modern horse's tooth, and when these are found buried in the ground, they are often thought to be the teeth of a gigantic extinct animal. These specimens are, of course, not fossils, nor are they pseudofossils: They are simply remains that are not old enough to be regarded as fossils.

FIG. 3. Tooth of a modern horse.

This should not discourage the reporting of suspected fossils. The true paleontologist is not disillusioned when he finds that the specimen at the end of his trip is nothing more than a horse or a cow, nor should he be annoyed with the individual who informed him of this "discovery." He should tell his informer, who will be much more disappointed than the pale-

ontologist, that his mistake was a natural one and perhaps next time he will find a real dinosaur.

It is often stated that if you can smell a specimen it is not a fossil, but even this may be subject to qualification because mummified specimens may be quite odoriferous once they have been removed from their dry cave or other environment.

3

A Fossil Collection

AFTER giving a lecture on fossils to amateurs, a geologist is usually asked, "Where can I find some fossils for myself?" This question is not always easy to answer and depends upon where the interested person happens to live.

We have discussed the three main types of rocks — sedimentary, igneous and metamorphic. Fossils are frequently found in the first, almost never in the second, and occasionally, although less well preserved, in the third. This may be very well, but how does the beginner know where to find the different kinds of rocks in his home region? Of course, if he has learned to distinguish between a sandstone and a granite, he will concentrate on the former and not waste any time on the latter. However, he may not know where to find a sandstone or other suitable fossil-bearing rock. What then can he do? He might spend days or weeks wandering around his home state looking for a suitable rock, or he might accidentally stumble upon a good fossil locality. There is an easier way and one that is recommended to the young paleontologist.

Most of our 50 states and the 10 provinces of Canada have geological surveys. Sometimes they are known by different names, but a little investigation should enable the interested person to locate them, but not always, in the state capital. Most of these surveys have published geological maps of their state or province. While these are not large enough to show every detail of the geology, they are very useful in showing

the main distribution of the different kinds and ages of rocks. These maps should be very helpful in guiding the would-be fossil collector to places where he has a reasonable chance of finding specimens.

A few states have issued popular or semipopular guides to their geology and these frequently list specific fossil localities. Among the states that have issued useful summaries are: Kentucky, New York, Ohio, Minnesota and Pennsylvania.

The United States Geological Survey in Washington has published a general geological map of the United States and has cooperated with many of the state surveys in mapping entire states or specific areas. A large series of *Folios* has been issued by the federal survey which maps certain areas in considerable detail (frequently one inch to a mile). While few if any of the United States Geological Survey's publications may be said to be written in "popular style," they often mention fossil localities and give more detailed information on the occurrences of rocks than is possible in any general state map. Unfortunately, many of these *Folios* are out of print, but they may be consulted in any large library. Some of them have been prepared jointly by the state and federal surveys. The Geological Survey of Canada also has issued valuable geological maps and reports.

Some private institutions (museums and the like) have issued guidebooks to local geology. There are also numerous local geological and Earth Science societies that will welcome the amateur and supply him with information on nearby fossil localities. Information on these various organizations can frequently be obtained through the state surveys.

With information gleaned from these various publications, the collector can narrow the limits of his search and can often learn the names of quarries or other localities where fossils can be obtained. The collector should be very careful not to attempt to collect from any quarry or other locality without

first obtaining permission from the owner or manager. This is a matter of common courtesy and will avoid embarrassment or unpleasantness.

HOW TO COLLECT FOSSILS

This will depend upon the kind of rock in which the fossils occur. In some places the fossils are loose in sand and clay and can be picked out by hand or with the aid of a penknife. More often they are in hard rock and must be chipped out. Again, the method may vary with the kind of rock and the wishes of the collector. A geological pick, with one blunt end and one pointed end, is the most useful all-around tool. This may be supplemented in some cases by a chisel. If the specimens are difficult to chip from the rock, it is good policy to take reasonably large pieces of the rock back to the home or laboratory and there to extract the specimens under more comfortable and less hurried conditions. The use of dental tools and toothbrush is recommended.

HOW TO KEEP FOSSILS

Again, this will vary with the circumstances of the collector. Not many people have the space to keep extensive collections, and it will probably be necessary to limit one's collection to the best material or fossils from specific areas. However, some amateurs have equipped special rooms or small museums for their collections. Others have available only a small amount of space.

Whatever one does with his collection, it is important that it be labeled and if possible cataloged. When an enthusiastic collector comes back from a day's trip he is positive that he will remember exactly where he obtained each specimen. How could he possibly forget any one of his treasures? However, when he goes on another trip the next day or the next week he

brings back more treasures. Even then, he is sure that he can't possibly mix his collections. But after numerous trips and a lapse of time, even the best memories will fade, and he will find himself beginning to wonder whether he found his fossil at locality *a* or locality *b*. In time, the collection will lose a great deal of its scientific importance when locality information is uncertain or missing.

The simplest thing to do is to put all material from a certain locality in a single box which is carefully labeled. Or if he wishes, he can put each species in a single box which again is carefully labeled. If this takes too much space, he can give the locality a number and place that number, either in ink or written on a piece of adhesive tape, on each specimen. He can then keep a catalog of localities and if he wishes of individual specimens. If he returns to a locality again and again, he can always use the same number. The exact date of collecting means little to the paleontologist. The fossils are millions of years old anyway, so what are a few more days, or years.

Many fossils can be kept in the condition in which they come from the rock. Others are so fragile that they require special treatment for preservation. A weak solution of shellac can be used as a coating for these fragile fossils. This is especially important for vertebrates. Very large bones require special treatment, but these rarely are part of the amateur's collection. Broken shells and bones can frequently be mended with cement.

The amateur cannot attempt to compete with a large museum, nor should he attempt to do so. A fossil or mineral collection can mean a great deal to a student or beginner and will enable him to understand much more about the earth on which he lives than would otherwise be possible. Many prominent geologists of today got their first insight into their future profession by collections of fossils or minerals made when they were still in school. Even if the collector does not choose Geology as his career, he will have a much broader apprecia-

tion of life if he understands something of the history of the earth and the fossils and minerals that can be found in its rocks. But let us add a word of caution, or rather advice. If the amateur finds a very rare or unique fossil, it would be well to call it to the attention of a professional geologist. If it turns out to be a new species or a new record for the area, it might be well to consider presenting it to a large museum, possibly the state museum or some other institution of equal standing. Thus, it will be available to all scientists for study and comparison. Private collections, while they are very helpful to the individual and encouraged by most professional geologists, are occasionally lost or mislaid when the amateur moves, or loses interest in the subject. Therefore, most scientists strongly urge that rare or unique specimens be given to a museum. The honor of having his name on the label should do much to compensate the owner for the loss of such a specimen from his collection.

4

How Fossils Interpret Geological History

DURING the Middle Ages it was almost heresy to state that the world was older than about 6,000 years. In fact this figure was proposed by Bishop Ussher of Ireland in 1654 from a study of the Old Testament by assuming that *all* events in history were recorded therein. The inclusion of this estimate of the origin of the earth—to be exact 4004 B.C.—in the religious thought of the time greatly retarded scientific investigations on the actual age of the earth.

Even during the Renaissance or Revival of Learning in the fifteenth and sixteenth centuries, there was a major difference of opinion regarding the origin of shells and other fossils that were dug from the earth. Some who truly recognize the meaning and antiquity of the fossils were discredited and actually persecuted. The more popular belief was that these objects were "devices of the devil" or "freaks of nature." Even when their true meaning was fully recognized, man regarded them as relics of the flood described in the Old Testament, and it was not until the nineteenth century that the concept of the really great age of fossils was generally accepted.

Finally the concept of a long period of geologic time began to be recognized by scientists.

Some of the earlier methods of measuring geologic time and of trying to determine the age of the earth were rather crude

and inaccurate compared with current methods, but are important because they show the realization that millions of years — not hundreds or thousands — were required to interpret the events that have taken place during geological history.

These methods include estimating the average rate of sedimentation per year and the consequent number of millions of years required for the many miles of sediment on the surface of the earth to have accumulated, as well as an estimate of the number of millions of years for the oceans to have received their present salt content — assuming that their waters were originally fresh. While both of these methods are regarded as being highly inaccurate, they did at least give the proper concept of a long period of geologic time.

With the development of studies in radioactivity early in the twentieth century, a new tool was found to determine the age of certain rocks and thereby to estimate the age of the earth.

Many igneous rocks contain the mineral pitchblende which is a uranium oxide. Uranium is known to disintegrate at a rate that is apparently constant under all circumstances of temperature, pressure and environment. Atoms of helium are emitted by the uranium and the end products of this disintegration are helium (He) and lead (Pb). Careful experiments have shown that 1 gram of uranium will yield 1/7,600,000,000 grams of lead per year. Thus, if we can determine the ratio between the lead and uranium in a rock we can determine the age of the rock by using the formula:

$$t = \frac{\text{Pb}}{\text{U}} \times 7{,}600{,}000{,}000$$

which means that the age of the rock *(t)* is equal to the lead uranium ratio times 7,600,000,000. This method is only applicable for unweathered igneous rocks, containing uranium minerals, and since there is a considerable error, it is gen-

erally used only for rocks of great geological age.

One of the newer methods of age determination is by means of radiocarbon (C_{14}). This is an isotope, or variety, of carbon that resembles ordinary carbon but which has a different atomic structure. Radiocarbon is present in the atmosphere and in all plants and animals in a definite ratio to ordinary carbon. After the animal or plant dies, the radiocarbon disintegrates at a known rate. Therefore, the ratio between the radiocarbon and ordinary carbon diminishes over a period of time and can be used to determine the age of the organism. The half-life of C_{14} is 5,558 years; in other words, the radiocarbon is half gone at the end of 5,558 years; it continues to disintegrate at a slower but known rate and is entirely gone or in such minute traces as to be unmeasurable at the end of about 35,000 years.

This method is very useful in determining the age of wood, charcoal, bone and some shells that are less than 35,000 years old. It has been very valuable in studies of archeology and geology and has resulted in establishing a fairly accurate chronology from the middle of the last glacial stage to the present time. While there is a possible error in this method, it is relatively small.

THE GEOLOGIC TIMETABLE

The generally accepted method of subdividing geologic time recognizes five major divisions called eras which are broken down into eleven periods. The estimates of years cited in the chart on page xiv are largely from reports issued by the National Research Council which in turn are based upon the latest studies of radioactive rocks. The estimate of the age of the oldest rocks, based especially on work in Finland and Canada, is about 4 billion years. It is possible that even older rocks will be found as this type of work continues.

ARCHEOZOIC ERA

This represents a very long interval from the time of the solidification of the earth until a stage, perhaps a billion years ago, when there was a great period of erosion. Little if any life was present during this era, and there was a considerable amount of volcanic activity and mountain building. For example, the Laurentians of eastern Canada were first uplifted during the Archeozoic.

PROTEROZOIC ERA

This era followed the long period of erosion and included stages of sedimentation, volcanic activity and glaciation. Some of the important mineral deposits of the United States and Canada were formed during this era. Life was present, but confined to very simple marine forms such as worms, sponges, jellyfish and brachiopods.

The two eras, Archeozoic and Proterozoic, are frequently spoken of collectively as the pre-Cambrian, and they will be so combined in this book.

PALEOZOIC ERA

Age of Invertebrates—Cambrian and Ordovician Periods.

This marks the real beginning of geological history, for our knowledge of pre-Cambrian events is very incomplete and sketchy. During Cambrian time, there were two inland seas in North America, one extending from the present Gulf of Mexico in Alabama to the Gulf of St. Lawrence, and the other roughly along the line of the Rocky Mountains.

An important land mass or continent which geologists call Appalachia extended along our east coast east of the Appalachian inland sea, and persisted throughout the Paleozoic Era and well into the next era, the Mesozoic. Life was entirely confined to the sea and consisted mainly of invertebrates or

animals without backbones although a few primitive fish also were probably present. The end of the Cambrian period was marked by a minor uplift of mountains in Vermont.

During the Ordovician the geography of North America was not very different from that of Cambrian time, although the seas were a little more widespread. The marine life was slightly more varied, although it was still almost entirely limited to invertebrate forms. Mountain building took place in New England and northeastern Canada at the end of this period.

Age of Fishes—Silurian and Devonian Periods

The sea continued to cover parts of North America during the Silurian period and there was a direct seaway from the Appalachian inland sea to the western Arctic by way of the Great Lakes, Hudson Bay and the Mackenzie region of Canada. During one part of this period, some sections of the ocean dried up, especially in New York, Michigan and Ontario, forming immense salt deposits which are mined today. Life in the sea became even more varied with the fish becoming more and more important. The first land plants are thought to have appeared during this period.

The inland seas advanced and retreated several times during the Devonian period and toward the end of the period new mountains were formed along the Atlantic Coast from Nova Scotia to southern New England which for a while blocked the northern entrance to one of the inland seas. Life became more highly devoloped, both on the sea and on land. The Silurian and Devonian periods are popularly called the Age of Fishes.

Age of Coal—Mississippian, Pennsylvanian and Permian Periods

By this time most of the inland seas had withdrawn from eastern North America leaving in their place some immense

swamps. These swamps with their luxuriant vegetation gave rise to the coal that is so abundant in certain areas today. The seas continued to cover portions of central and western United States, especially in the Mississippi Valley. The combined Mississippian and Pennsylvanian periods are frequently spoken of as the Carboniferous.

Coal formation continued into the Permian although it was limited to parts of western Pennsylvania, West Virginia and Ohio. The climate during part of Permian time was very dry causing deserts to exist over a wide area from Kansas southwest to New Mexico, although at times this area was covered by a shallow sea. The end of Permian time was marked by a period of mountain building which produced the ancestral Appalachian Mountains from Alabama to Maine. This marked the end of the Paleozoic Era.

MESOZOIC ERA

Age of Reptiles—Triassic, Jurassic and Cretaceous Periods

Very little of North America was covered by the sea during the Triassic period. There were no inland seas in the East and only a few shallow bays in the West. A series of fresh-water lakes or basins extended along the Atlantic Coast from Nova Scotia to Georgia or beyond. These existed between the ancient continent of Appalachia and the recently uplifted Appalachian Mountains.

The end of the period was marked by an earth movement called the Palisades Disturbance which gave rise to the Palisades of the Hudson River as well as some other hills. This was the beginning of the Age of Reptiles which was to continue throughout the Mesozoic Era with an abundance of dinosaurs, and other large reptiles.

By Jurassic time the land mass Appalachia had nearly eroded away and the eastern part of the continent was a gently sloping plane with few or no arms of the sea extending

beyond the present shore line. Dinosaurs and other reptiles reached their peak of development during the Jurassic. The Sierra Nevadas of California were uplifted during this period.

During Cretaceous time the seas covered up to 50 per cent of North America. At the time when the greatest amount of land was submerged, the entire Atlantic and Gulf coastal plains were covered by a shallow sea which also extended up the Mississippi Valley to southern Illinois. At the end of the period there was great mountain building (Laramide Revolution) which produced the Rocky Mountains. Dinosaurs and many other large reptiles died out at the end of the period, while mammals were just beginning to be in evidence. Marine life of the seas was abundant, and began to be more like it is today.

CENOZOIC ERA

Age of Mammals—Tertiary Period

Except for a narrow arm of the sea which extended up into the Dakotas from the Gulf of Mexico during the very early Tertiary time, western North America was entirely above the sea during the Tertiary. There were, however, numerous lakes and basins in Utah, Wyoming, Colorado, etc. The eastern part of the continent was intermittently covered by a sea, but this did not advance as far as those of the Cretaceous period. The Tertiary period is divided into five subdivisions or epochs and since these names will be used frequently in connection with the fossils and minerals described later they are listed here, in stratigraphic order, that is, with the youngest on top.

5. Pliocene ("more recent")
4. Miocene ("less recent")
3. Oligocene ("a little recent")
2. Eocene ("dawn recent")
1. Paleocene ("ancient recent") sometimes combined with Eocene

The mammals were the dominant land animals of the Tertiary, while the marine life had an even more modern appearance than that of the Cretaceous.

The Ice Age—Quaternary Period

For convenience this period can be divided into two epochs:

2. Recent
1. Pleistocene ("most recent")

The boundary line between the two is not very definite, but may be regarded as the time when the last great glaciers began to retreat, probably about 12,000 years ago.

The Pleistocene is sometimes spoken of as the Great Ice Age because of the many glaciers which advanced from the polar regions over the continents. It is believed that there were four major glacial stages separated from each other by three interglacial stages when the climate was somewhat warmer causing a partial melting of the glaciers. It is believed that the interglacial stages were longer than the glacial stages and that there were minor variations of climate in each stage. According to many scientists, our climate is slowly becoming warmer and we are approaching another interglacial stage. The seas rose and fell as water was added to and taken away from them to form the land ice, but at no time were any great areas of the land covered by the ocean. The Coast Range of the Pacific Coast was uplifted during the Pleistocene.

This latest chapter of geological time is also known as the Age of Man because he became the dominant creature on earth during this period, just as the reptiles had been dominant during the Mesozoic Era.

5

Fossil Invertebrates

WE HAVE SEEN what fossils are and have discussed the various ways in which they may be preserved and how they are used to interpret the geological history of the earth. The student of fossils, whether amateur or professional, will want to know more about his collection, especially what kind of animal or plant they represent. To do this he must know something of biological classification.

Plants and animals have two names, just like human beings. The genus represents the family name such as Smith, Jones, or Brown, while the species name corresponds to the Christian name such as John, James, or Mary. Just as an individual has two names, John Smith, an animal will also have two names, *Felis domestica* (domestic cat), although, contrary to custom in humans, the genus name (equal to the family name) appears first. Animals related to *Felis domestica* such as *Felis leo* (lion) show their relationship by having the same genus name but a different species name, just as it is apparent that John Smith and James Smith are related. Biologists are very particular in their naming of animals and plants and there can be no duplication of names. There can be only one *Felis domestica*,[1] although there are countless John Smiths in the world. A genus name cannot be duplicated except that a plant and animal may possess the same name; a species name

[1] The various breeds of cats are all regarded as *Felis domestica*.

may be duplicated, but not in combination with the same genus. There may be a *Pecten grandis* and an *Ostrea grandis*, but no more than one of either combination. Complicated rules have been set up for the naming of animals and plants which must be followed by all biologists and paleontologists in order to avoid confusion.

Biologists divide the animal kingdom into two unequal parts —the Protozoa or single-celled animals and the Metazoa, the many-celled animals. The Protozoa constitute a single phylum or major division, while the Metazoa comprises many phyla (8 to 35 depending upon the ideas of the classifier). Phyla are subdivided into classes, orders and families.

PROTOZOA

It seems entirely unreasonable to expect such microscopic forms as amoeba and paramecium to be preserved as fossils. In fact, of the many varieties of Protozoa, representatives of only two orders are at all conspicuous in the fossil records. These are the Radiolaria and the Foraminifera, the latter being by far the more important.

The Foraminifera (or "forams" as they are often called for short) may be thought of as shelled amoebas, the shells being of calcareous, chitinous, or sandy material. The shells are generally external and are secreted by the organism. They consist of various chambers, and in most cases there are minute openings, or foramina (hence the name Foraminifera). The size, shape, and arrangement of the chambers have much to do with the classification of this group of organisms.

Although most Foraminifera are minute or even microscopic, a few attain the size of an inch or more and even giant specimens up to 4 inches in diameter have been recorded.

Foraminifera have existed in the oceans throughout most of recorded geologic time, although they are not conspicuous in rocks earlier than the Mississippian. Because of their

TABLE OF ANIMALS

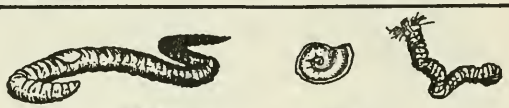
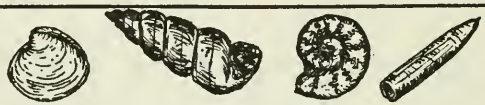
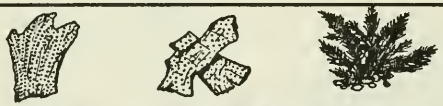
CLASSIFICATION	ILLUSTRATIONS
CHORDATA	
ARTHROPODA	
ANNELIDA	
MOLLUSCA	
BRACHIOPODA	
BRYOZOA	
ECHINODERMATA	
COELENTERATA	
PORIFERA	
PROTOZOA	

FIG. 4. Pictorial table showing the most important major divisions (phyla) of animals.

abundance, their small size, and the ease with which they may be collected, Foraminifera are widely used by oil geologists to mark specific formations either on the surface of the ground or in samples obtained from wells.

Fig. 5. *Fusilina.*

Let us examine a few characteristic species of Foraminifera.

Those belonging to the genus *Fusilina,* have the same size and shape as a grain of wheat. They were very abundant during Pennsylvanian and Permian times, and died out at the end of the Paleozoic Era. Upon examination, they all look very much alike. However, when they are sectioned and examined under the microscope, a great variation in the arrangement of the chambers can be seen, and it is these variations that differentiate the various species. Fusilinids may be looked for in rocks of appropriate age, Pennsylvanian and Permian, in Oklahoma, Kansas, and Texas.

Fig. 6. *Numulites.*

Some varieties of Foraminifera are large enough to be seen with the naked eye. Those belonging to the genus *Numulites* are a little less than an inch in diameter and look like small sand dollars. They were very abundant in the Eocene seas of the Mediterranean region. In fact limestone containing multitudes of them was used for the great pyramids of Egypt.

Other genera of Foraminifera, large enough to be seen with the naked eye, occur in early Tertiary rocks of the United States. Again, they look very much like small sand dollars and they must be sectioned before their classification can be worked out. Vari-

ous species of *Lepidocyclina* and *Orbitoides* occur in the Eocene limestones of Georgia and Florida.

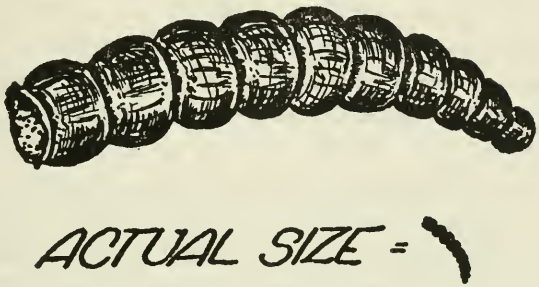


Fig. 7. *Nodosaria.*

In general, the Foraminifera of Cretaceous and younger age are minute and can barely be seen with the naked eye. One common genus, just large enough to be seen without a lens (1/8 inch), is *Nodosaria* which looks like a chain of beads.

METAZOA

PORIFERA (Sponges)

Everyone knows the bath sponge—or did before the days of synthetic sponges—but it may come as a surprise to some that this common object is actually the remains or skeleton of a marine animal. Once sponges were regarded as plants, and it was not for some time that their animal nature was established. Even then, their position in the animal kingdom was not clear. Some maintained that they were microscopic unicellular colonies. Their multicellular nature was finally established after a careful microscopic study of their structure, and now they are generally regarded as among the simplest of multicellular animals (Metazoa).

Sponges belong to the phylum Porifera, meaning pore-bear-

ing. This name was given to them because of the numerous pores scattered over the surface. These pores usually lead to a central cavity which in turn opens to the outside through an aperture called the *osculum*. Water is constantly flowing through these canals and the sponge obtains its nourishment from the microscopic animals and plants that pass through its body. Thus, in a sense, it may be said that the sponge is always eating!

The flesh or soft part of a sponge is strengthened by a framework or skeleton of needle-like structures called *spicules*. In fact, the classification of these animals is partly based upon the structure and shape of these spicules. The most common kinds of spicules are of calcareous (lime-like), siliceous (glass-like), and horny material while a few sponges have no spicules at all.

Most sponges are marine, although a few varieties, such as the small green sponge, can be found in fresh water. They can be found in most seas, although the common bath sponge prefers warm tropical waters such as the South Atlantic, the Gulf of Mexico or the Mediterranean. Important sponge fisheries are located at Tarpon Springs, Florida, Nassau, Bahamas, and at various places along the coast of Greece and Italy. At these places one can see great quantities of sponges drying near the shore where they have been brought by the sponge divers from the depths of the ocean.

While the bath sponge is of value to man, other sponges do harm. One of these, the boring sponge (or sulphur sponge), attaches itself to sea shells, especially those of the clam or oyster and slowly bores holes in the shell until eventually the shell is completely riddled, with the result that the clam or oyster dies. Thousands of dollars' damage is done every year to the oyster industry by this boring sponge. Shells containing these holes are frequently found on our beaches.

Apparently the ancestors of the boring sponge have had

this same destructive habit for millions of years, for oyster shells riddled by this same kind of hole have been found in deposits as old as the Cretaceous period, 75,000,000 years ago.

While sponges are fairly common in most seas and are frequently washed up on the beach, the fossil representatives of this group of animals are relatively rare. The reason for the scarcity of fossil sponges is rather obvious. Except for their framework of spicules, sponges are relatively soft objects, and are not very likely to be preserved as fossils. True, the spicules themselves may be preserved, but in most cases the rest of the animal decays soon after death. In fact, a microscopic examination of many marine sands or clays frequently reveals the presence of a great many spicules, but it is generally impossible to determine the identity of the sponge, or even its size and shape.

While sponges are not common as fossils, they have been

FIG. 8. A globular shaped sponge, *Microspongia,* from the Ordovician of Tennessee.

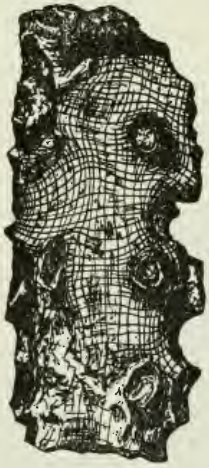


FIG. 9. The Glass Sponge, *Hydnoceras,* from the Devonian of New York.

found in rocks of all geological periods from the pre-Cambrian to the Recent. Probably the best collections of fossil sponges have come from the Devonian rocks of New York and the Cretaceous chalks and limestones of Europe.

Of the many kinds of sponges that might be found, let us examine only three—one from the Ordovician, one from the Devonian, and one that might have lived at any time between the Cretaceous and the present day.

Small round objects, about the size of a golf ball, are common in the limestones of western Tennessee, especially near Perryville. At first glance these look merely like limestone pebbles or concretions, but millions of years ago they were living sponges not so very different from some inhabitants of tropical waters that we know today. These have been given the name *Microspongia.* If we examine some of these fossils carefully, we will note that many show a shallow hole at the top. This is the remains of the osculum. How different this part of Tennessee must have looked some 450,000,000 years ago when it was the bottom of shallow sea!

Another interesting sponge is *Hydnoceras* or the glass sponge. These were erect vase-like animals averaging 8 inches in height, that frequently grew in large clusters in the Devonian seas of southern New York. These sponges show faint ridges running up and down and around the body. Where these ridges cross there were clusters of needle-like siliceous or glassy spicules. However, one may look in vain for these spicules, because they have been frequently worn away by weathering and erosion.

Fig. 10. A Conch shell with holes made by *Cliona.*

A close relative of the Devonian glass sponge is the Venus flower basket of the modern seas near Japan.

We have already spoken of the boring

sponge or *Cliona* that does so much damage to oysters and other shellfish. One may look for this on our modern beaches or in fossil deposits dating back as far as the Cretaceous. For example, Figure 10 shows a conch shell from Pleistocene deposits near Cape May, New Jersey, riddled by this sponge. Similar specimens could have been collected in the Miocene deposits of the Chesapeake Bay region, the Cretaceous deposits of Texas, or the Pleistocene deposits of southern California.

COELENTERATA (Jellyfish, Corals, etc.)

The third main group or phylum of animals is known as the Coelenterata, meaning hollow intestine, which includes such varied forms as the little green hydra of fresh-water ponds, simple marine animals known as hydroids, the jellyfish, sea anemones, corals, and several lesser-known groups of animals.

Since a jellyfish is about 98 per cent water, its chance of preservation as a fossil is exceedingly small. In all but a very few cases, jellyfish disintegrate rapidly upon death. A few forms have been preserved, and from these we know that jellyfish have remained almost unchanged since pre-Cambrian time, more than half a billion years ago.

One must search for a long time before finding fossil jellyfish, and even when they are found, it is often difficult to recognize them for what they are.

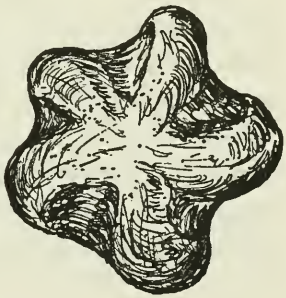


FIG. 11. Fossil jellyfish, *Brooksella,* from the Cambrian rocks of Alabama.

Well-preserved fossil jellyfish have been found in rocks of Cambrian age at a very remarkable locality near Field, British Columbia. Here a certain kind of fine-grained shale called the Burgess shale has preserved fossils so perfectly that many details can be observed, even of such soft-bodied creatures as jellyfish.

Other fossil jellyfish, not nearly so well preserved, have been found in Cambrian deposits in Alabama and Montana, Ordovician shales in New York and Cretaceous deposits in Texas.

While there are several other classes of Coelenterata, by far the most important for the student of Paleontology is the class Anthozoa which includes the corals and their relatives.

Corals are animals or polyps which secrete calcareous skeletons. After a few years the animals die, but the skeleton remains sometimes forming immense masses known as reefs. In fact, entire islands may be made of the skeletons of ancient corals. Corals may be solitary or colonial, the latter, of course being the ones which form the great reefs.

Most corals require three conditions for their existence: warm water—not under 68° F; shallow water—not more than 135 feet; and clear water, that is, without too much mud. Consequently, coral reefs are to be found today in most tropical seas including the Caribbean, the South Pacific and the Red Sea. A few corals, such as the common star coral (*Astrangia*) of the Atlantic Coast, can stand fairly cold water and are to be found living today as far north as Cape Cod. Small coral reefs are known from the west coast of Norway as far north as Trondheim (latitude 63° N), although here the water is warmer than might be expected because of the presence of the Gulf Stream. Some small corals have also been found living off the coast of Antarctica.

Since coral reefs today are restricted to warm seas, most geologists assume that this was always the case, and therefore

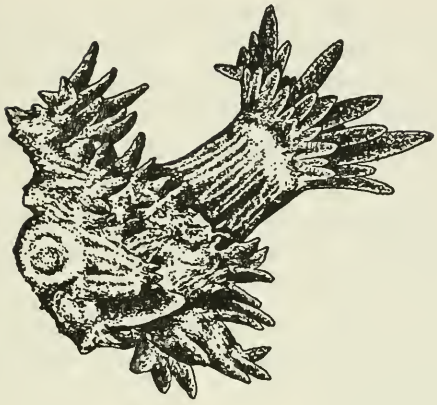


FIG. 12. Living Star Coral, *Astrangia danae,* showing the expanded polyp.

when fossil coral reefs are found in temperate climates, we have strong evidence that the climate in that part of the world was once warmer than at present. The finding of extensive fossil coral reefs in Devonian rocks in the Far North, for instance in the Mackenzie Delta of Canada or along the shores of Hudson Bay, as well as in rocks of the same age in temperate or tropical zones, suggests that the climate must have been rather uniform throughout the world during that geological period.

True corals made their appearance during Ordovician time. At first they were small and inconspicuous, but by the end of that period some of the reef-building corals had become fairly numerous. By Silurian time, corals were exceedingly abundant and formed a large part of the life of the seas. Extensive reefs were formed in such widely separated places as upper New York, Illinois and Michigan.

By Devonian time the corals had reached a climax. Large parts of North America were covered by shallow warm seas

affording excellent habitats for these animals. Devonian corals are abundant at many localities, for example in western New York, near Stroudsburg, Pennsylvania, in Kentucky (Falls of the Ohio River), and in Iowa, where the town of Coralville in Johnson County, was named for the very many fossil corals found in quarries in that vicinity.

During Carboniferous and Permian times, corals were relatively inconspicuous and were generally limited to small solitary types, such as those found in Pennsylvanian rocks of Texas. For some strange reason, not yet understood, extensive fossil coral reefs of Pennsylvanian age exist in the Arctic Ocean at Spitzbergen.

Corals continue to live in the seas, although those of the Mesozoic and Cenozoic belonged to different families than those of the Paleozoic. Nowhere in North America were corals as abundant during the Mesozoic and Cenozoic as they had been during the earlier periods, especially the Silurian and Devonian.

It will be impossible to describe all the species that might be found by the collector, but we can mention a few of the more common types.

FIG. 13. Devonian Horn Coral.

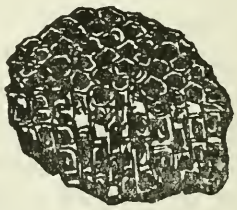


FIG. 14. Honeycomb Coral, *Favosites,* common in Silurian and Devonian rocks.

There are many kinds of corals that come under the general name of horn coral or cup corals. Their main characteristic is that they are solitary as contrasted to the colonial or reef-building forms. They are known from marine deposits from the Ordovician to the Permian, but are especially common in Ordovician, Silurian, or Devonian rocks.

A cup-like shell was secreted by the animal (polyp), and this shell is divided internally by a series of partitions called *septae.* The arrangement of these septae partly determines the classification of the corals.

Horn corals or cup corals were abundant, often associated with colonial forms, in great reefs in the seas which covered large portions of the North American continent during parts of the Paleozoic Era. New York, Pennsylvania, Ohio, Illinois, Iowa, and Michigan are just a few of the places where this kind of fossil can be found today.

One of the most frequently found fossil coral is the honeycomb coral *(Favosites).* In this form the septae are not very conspicuous, but there are horizontal tabulae (plates) in the tubes that make up the colonies.

The reason for the popular name honeycomb is obvious. This form is colonial with the individual members of the colony prismatic in form. Many species have been described from both Silurian and Devonian rocks.

The chain coral *(Halysites)* also has an appropriate common name. The individual members of this colony are arranged in a chain-like network which is especially apparent when it has been partly weathered. Like the honeycomb coral, it has no septae, the main partitions being the tabulae. It is abundant in Silurian and Devonian rocks, especially in New York, Ohio, Illinois and Michigan.

In the star coral *(Astrangia)* the septae are well marked. One species, *Astrangia danae,* lives today between Cape Cod

and Florida and is one of the few species that is able to live in water as cool as that of the New England Coast. The members of the colony are relatively small (¼ inch) and the colonies themselves rarely exceed a foot in size. The septae are developed in multiples of six. Other species of *Astrangia* are found in Tertiary and Pleistocene rocks along the Atlantic coastal plain.

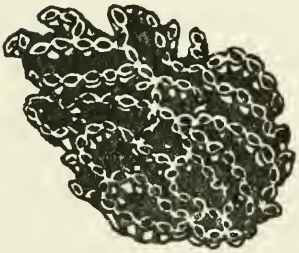


Fig. 15. Chain Coral, *Halysites,* also common in Silurian and Devonian rocks.

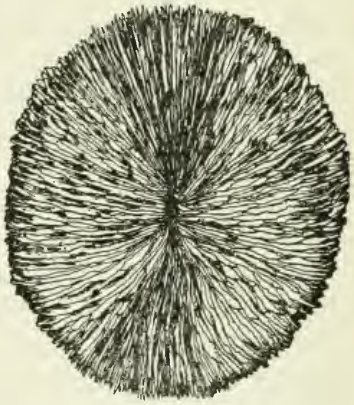


Fig. 16. Modern Hexacoral from the Red Sea.

In Mesozoic and Cenozoic corals, the septae are developed in multiples of six, while in the case of the Paleozoic colonial forms, they develop in multiples of four. This difference is very important in the classification of corals. An example of a modern hexacoral from the Red Sea is shown in Figure 16. Another coral-like form which is present in many tropical seas today is the staghorn coral, or *Millepora.* Technically, it is a hydrocoral rather than a true coral, although it has the same habits and many of the characteristics of the reef corals that live in the same waters. If one examines the skeleton of

a staghorn coral with a hand lens, he will see a great many small openings or pores. These pores were the homes of the coral polyps. This form is common, both fossil and living, in the West Indies.

ANNELIDA (Worms)

FIG. 17. The Hydrocoral, *Millepora.*

It need hardly be stated that worms are not important as fossils. The chances of complete preservation are exceedingly small, and one may search long before finding a positively identifiable fossil worm.

While many worms are free-living, there are numerous species that build tubes of sand, mud, or shell, and it is these tubes that are occasionally preserved as fossils. The size, shape and ornamentation of the tube is frequently characteristic of a specific worm, and thus the tubes are named in the same manner as if they were the fossil worms themselves. This illustrates the importance of the word trace in the definition of a fossil as given earlier.

Sometimes even the tube disintegrates, although the mud or sand which filled the tube retains the original size and shape. For example, several species of the worm *Hamulus* in the Cretaceous deposits of the Atlantic coastal plain are recognized mainly on the fillings of the tubes. These are important because certain tubes are characteristic of specific formations, making these worms good index fossils.

Calcareous or shell-like tubes are the most suited for preservation, and are found attached to shells and other objects of most geologic periods. These tubes may be straight, curved, or coiled and are frequently known by the general term "serpulid."

FIG. 18. Cambrian sandstone showing the tubes of the worm *Skolithos*.

FIG. 19. Mud filling of a tube of the worm *Hamulus* from the Cretaceous of New Jersey.

FIG. 20. Coiled worm tube, *Serpula*, from the Paleocene of New Jersey (enlarged x 6).

ECHINODERMATA (Spiny-skinned animals)

The next phylum comprises the echinoderms, or spiny-skinned animals. The phylum is divided into two parts whose technical names need not concern us, but which might be thought of as the attached and free-moving echinoderms. Let us first examine the attached forms.

The most primitive of the group are the cystoids. These are globular in shape and are attached to the sea floor, either directly or by means of a stalk. These are very rare as fossils and lived only from the Cambrian to the Permian.

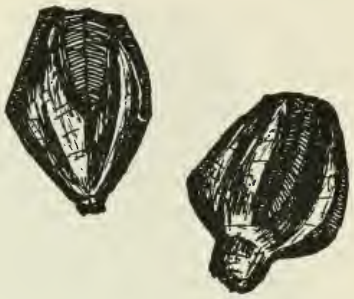


FIG. 21. *Pentremites.*

The blastoids, or sea buds, are related to the cystoids, but are generally more complex and probably represent a development from the cystoids. Like the cystoids, the calyx was attached to the substratum either directly or by a stalk and like the cystoids the calyx was made up of a series of plates. However, in this case the plates were regular, that is, of uniform size and shape. Also unlike the cystoids they usually possessed a large number of small arm-like structures called brachioles which, incidentally, were usually detached before the animal was fossilized.

The best-known blastoid is *Pentremites* which is fairly common in rocks of Mississippian age in the Mississippi Valley and the western United States.

The blastoids made their first appearance in the Ordovician, reached their peak in the Mississippian, and then went into a rapid decline and were entirely extinct by the end of the Paleozoic Era.

The crinoids are the best known of the attached echinoderms, and the only ones that are still living. They go by the common names of sea lilies, or feather stars. Until about a hundred years ago it was thought that the crinoids, like the cystoids and blastoids, were extinct, but it is now known that a great many varieties live in our modern seas, chiefly in the Caribbean Sea, the Pacific and Indian oceans. Crinoids today generally prefer moderately deep water, although they have been found at various depths from the intertidal zone to more than 15,000 feet.

A typical crinoid consists of three characteristic parts: (1) the head or calyx, usually a globular structure from which

FIG. 22. A crinoid, or Sea Lily, from the Triassic of Germany.

project (2) the arms or brachia which are much more conspicuous than the brachioles of the blastoid. The calyx is attached to (3) the stalk which may divide into several branches at its base known as cirri or roots. By the movement of its arms the crinoid is able to deflect the water current toward its mouth, which is situated on the upper part of the calyx, and thus is able to obtain the minute organisms (animals and plants) that it uses as food.

The crinoids made their first appearance in late Cambrian time and existed in great numbers throughout the rest of the Paleozoic Era. They probably reached their peak in the Devonian or Mississippian and then began a slow decline.

Complete fossil crinoids are not too easy to find, although some splendid examples have been found in Silurian and Devonian rocks of New York and Iowa and in Mississippian

rocks of Iowa, Indiana, Illinois, and the Canadian Rockies.

While complete specimens of fossil crinoids may not be too easy to come by, fragments of their stalks are frequently exceedingly common. These stalks are composed of joints of uniform or variable size through which there is an opening or *axial canal*. The shape of this opening may vary, but in general the stalk of a crinoid may be likened to a pile of doughnuts. The length of the stalk may vary from less than an inch to tremendous stems more than a yard in length. Stalks may be found in cross section (Fig. 23) or in longitudinal section (Fig. 24).

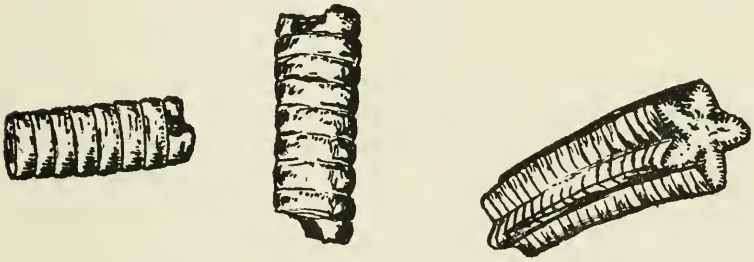


FIG. 23. FIG. 24.

Portions of stalks of two crinoids: rounded type and star-shaped.

Crinoids apparently lived in large colonies or reefs. In fact, some rocks such as the limestones of Indiana are spoken of as crinoidal reefs. (Some of these are important reservoirs of oil.)

The free-moving echinoderms are probably more familiar than their attached relatives. Most familiar of all the echinoderms, at least to the average reader, are the many varieties of starfish or asteroids. These animals consist of a central disc and usually five tapering rays or arms. In some species the arms occur in multiples of five while in many species individuals may be found with four, six, seven, or other num-

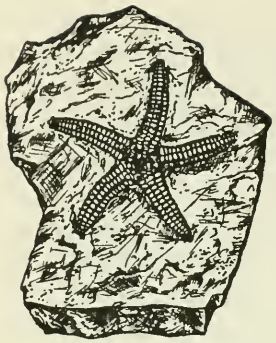


Fig. 25. Fossil starfish embedded in rock.

bers of arms. The starfish, like many primitive invertebrates, possesses the power of regeneration. An arm of a starfish may be devoured by a fish temporarily giving the animal only four arms; normally the arm will grow back, but sometimes by a "freak of nature" two or more will grow in the place of the injured arm thereby accounting for the "monsters" of six or seven arms.

The mouth of the starfish is at the center of the underside. This leads into the stomach which occupies the center of the disc with projections into the various arms. Extending from the mouth to the tips of the various arms are grooves known as ambulacral grooves. In these grooves are situated a large number of small tube-like projections, known as the tube feet. These are the locomotive organs of the starfish. Since water flows through these "feet," it may be said that the starfish moves by hydraulic power.

Today the starfish is one of the greatest enemies of the oyster and a great menace to that industry. Every year starfish kill thousands of young oysters, causing great loss to oystermen all along the coast.

While the average collector will not find many perfect fossil starfish, fragments may be looked for in almost any formation from Ordovician to the Pleistocene.

Serpent stars or brittle stars differ from the true starfish in that their arms do not possess ambulacral grooves and that the viscera are confined to the central disc without extending into the arms. The arms are serpent-like and are frequently used for locomotion.

Another group of echinoderms called the echinoids includes

the sea urchins, sand dollars and their relatives. Like the starfish, they are free-moving echinoderms, but instead of being star-shaped, they are usually globular or disc-like in appearance. The globular ones constitute the sea urchins (sometimes called sea eggs or sea porcupines) while the flattened ones are the sand dollars.

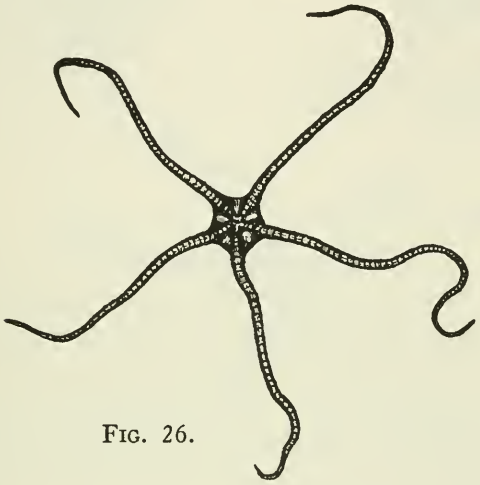


FIG. 26.

The shell-like test is almost entirely covered with small rounded tubercles to which are attached movable spines. Only on rare occasions can fossil echinoids be found with the spines attached. On the other hand tests and detached spines and tubercles are frequently found, especially in formations of Cretaceous or younger age.

The sand dollar is a flattened sea urchin with the spines usually greatly reduced in size. Various species are known from Tertiary and Pleistocene deposits along both Atlantic and Pacific coasts. They can often be recognized in fossil deposits even if present only as fragments.

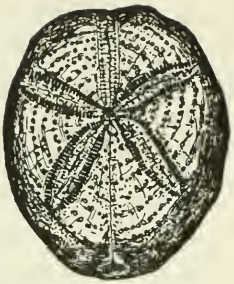


FIG. 27. Sea Urchin or Echinoid, *Eupatagus*, from the Eocene of Florida.

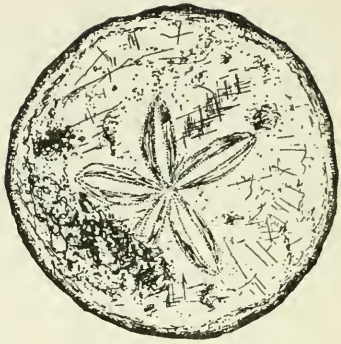


FIG. 28. Sand Dollar.

BRYOZOA (Corallines)

Although this group of animals is little known to the average collector, it forms an important part of the marine life today and has been present throughout much of geologic time.

Bryozoa are colonial forms, some of them superficially resembling corals — hence one of their popular names, *corallines*. The individual member of the colony is called a zooid which is enclosed in a membranous or calcareous cup or compartment called the *zooecium*.

Bryozoa made their first appearance in the Cambrian and have been present in all geological periods and epochs, although there were certain times when they were especially conspicuous, notably the Devonian, Mississippian, and Eocene.

Although Bryozoa are abundant in many rocks, their identification is not always easy. Parts of the skeleton are often destroyed during fossilization and furthermore many of the distinguishing features are very small and can only be seen by careful microscopic examination. Some typical examples of Bryozoa are shown in Figures 29, 30 and 31.

FIG. 31.

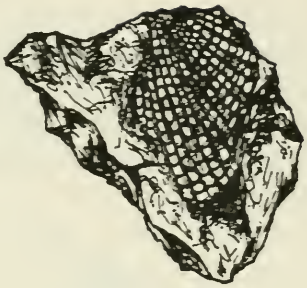


FIG. 30.

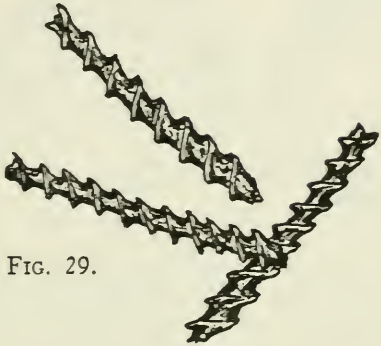


FIG. 29.

Three examples of Bryozoa: (29) *Archimedes* (Ordovician); (30) *Fenestella* (Devonian); (31) *Escharella* (Paleocene).

BRACHIOPODA (Lamp Shells)

Brachiopods or lamp shells are sometimes confused with bivalve mollusks, although they are much lower in the scale of animal life. It is true that both bivalves and brachiopods consist of two shells, but there their similarity comes to an end. Brachiopods have two shells that are dissimilar although the two halves of a single valve are symmetrical, in other words are mirror images of each other. The bivalve has two shells that are similar (with a few exceptions), while the two halves of each shell are quite different. In most brachiopods

the shell of one valve is thicker than the other and the beak of one overlaps the other valve. Most brachiopods are attached either directly to the substratum or by a stalk, while the great majority of bivalves are free living. There are, of course, also many anatomical differences between these two kinds of animals.

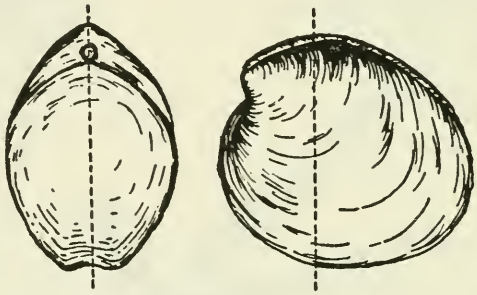


FIG. 32. Sketch showing the difference between a brachiopod and a bivalve. The brachiopod (left) has unequal shells but the two halves of the individual shell are mirror images of each other. The bivalve or pelecypod (right) has two valves which are mirror images of each other, while the individual shell is made up of unequal halves.

Brachiopods are one of the most abundant fossils in Palezoic rocks. They made their first appearance in the pre-Cambrian, although until the late Cambrian their shells were very thin with the result that their fossil remains are not too plentiful. However, from the late Cambrian until the end of the Paleozoic, they probably constituted the main element of the life of the seas.

The bivalves and other mollusks made their appearance a little later than the brachiopods and remained relatively inconspicuous throughout the Paleozoic Era. However, by the

beginning of the Mesozoic Era (Triassic time), the situation changed; the brachiopods became greatly reduced in number while the pelecypods and other mollusks expanded their development very rapidly. By the end of the Mesozoic (Cretaceous) the brachiopods formed only a small percentage of the shellfish of the oceans.

One of the most primitive brachiopods of present seas belongs to the genus *Lingula,* a genus that has remained unchanged for some 400 million years, or since Ordovician time, while genera not very different from *Lingula* lived in the Cambrian and pre-Cambrian. Figure 33 shows an example of this genus from the Ordovician deposits near Cincinnati, Ohio. It is a small tongue-shaped shell with a pointed beak; it was attached to a stalk (never preserved in the fossil form) which was partially buried in mud along the shores of this ancient sea. Forms not so very different from the one figured can be found in some oceans today.

Probably the most characteristic brachiopod of all times is *Spirifer* (now divided into numerous genera) commonly called the butterfly shell. It has a characteristic shape with each valve suggesting a butterfly with pointed outspread wings. The conspicuous groove on one shell with corresponding furrow on the opposite shell, is characteristic of this genus.

A tremendous number of species of *Spirifer* have been described from rocks of Devonian and Carboniferous ages. The individual species are recognized by difference in shape, size and sculpture.

The brachiopods of the Mesozoic, although greatly reduced in numbers, were the direct descendants of those of the Paleozoic. One form, known as *Christothyris,* which is characteristic of the Cretaceous, is shown in Figure 35. Note the dissimilar valves and the identical halves of the individual valve. The hole (foramen) where the stalk protruded can also be seen.

FIG. 33.

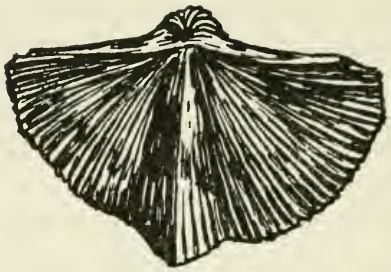


FIG. 34.

FIG. 35.

Three typical brachiopods: (33) *Lingula* (Ordovician); (34) *Spirifer* (Devonian); (35) *Christothyris* (Cretaceous).

MOLLUSCA (Clams, Snails, etc.)

This is one of the most conspicuous phyla of invertebrates and has been subdivided into numerous classes of which only three will be discussed in this book.

Pelecypoda are the bivalves and include such common forms as the oyster, clam, scallop and mussel. While the majority of them live in the ocean, some have adapted themselves to fresh water and are to be found in ponds, streams and lakes.

As mentioned under the brachiopods, a bivalve clam is distinguished from a brachiopod in several important respects, notably by the fact that the shells of the bivalve are similar but not equilateral. (See Fig. 32) There are, of course, apparent exceptions to this rule, notably the common oyster

which usually has unequal shells. However, this may be regarded as aberrant since the oyster when very young does have equal shells. The change to unequal shells may be thought of as an adaptation to a sedentary life. The same is true of certain scallops and other bivalves.

The bivalve shell possesses a beak. From this initial point one may usually see concentric lines marking stages in the growth of the individual. The two valves are held together by muscles which are attached to both shells. Teeth and sockets are usually present near the beak which also tend to keep the two valves together. The pattern and arrangement of these hinge teeth play an important part in the classification of bivalve mollusks.

Pelecypods have lived from the Cambrian to the present day. Although they are known as fossils in many Paleozoic formations, they did not achieve the importance of the brachiopods until the Mesozoic Era. From the beginning of Triassic time onward they have been increasing in numbers and importance.

Mesozoic clams, although frequently closely related to those of present seas, usually belong to different species and sometimes different genera. One of the characteristic pelecypods of the Cretaceous period is the genus *Exogyra*. As can be seen from Figure 36 this somewhat resembles the modern oyster, although it is obvious that it belongs to a different genus. *Exogyra* must have been abundant in the Cretaceous seas which covered the Atlantic and Gulf coastal plains, as well as many parts of Europe.

Clams are far too familiar to the average reader for us to devote much space to their description. Fossils of this group are readily recognized as such, although it will require a specialist to identify the genus and species.

Just as the pelecypods we know live in both salt and fresh water, so were the fossil clams distributed in these two environ-

FIG. 36. Large clam, *Exogyra,* of Cretaceous age.

ments, although, as today, the marine forms greatly outnumbered those of fresh water.

Any marine fossiliferous deposit of Cretaceous age or younger will undoubtedly contain numerous fossil pelecypods. In some places great shell beds occur which give us some idea of the abundance of these forms in the geologic past.

Gastropoda are the snails, sometimes called univalves. The name Gastropoda literally means stomach-footed animals and is used because the foot is really a thickening of the surface of the animal, giving the impression that the animal walks on its stomach. Gastropods are generally coiled or spiral although

FIG. 37.

FIG. 38.

Two Cretaceous clams: (37) *Panope,* (38) *Cardium.*

a few have rather peculiar shapes and some, such as the slugs and nudibranchs, possess no external shell whatever.

The top of the shell is called the *apex* and each turn of the spiral is known as a *whorl.* The line between two adjacent whorls is known as a *suture,* and when there is an open space or angle between the whorls, the area is called a *shoulder.* The last whorl in which the animal lives is called the *body whorl,* all the others being known collectively as the *spire.* The sculpture of the shell is often very ornamental and is of importance in differentiating the various genera and species. The opening through which the animal projects is called the *aperture* and in some species this is covered with a horny or calcareous lid called the *operculum.*

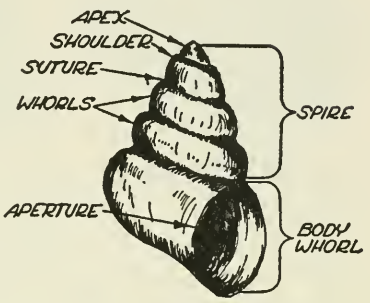


FIG. 39. Typical gastropod.

Gastropods today can be found in salt water, fresh water and on land, and their fossil ancestors also occupied these three environments, although the great majority of fossils are of marine species. Their earliest record is in the early Cambrian, although they, like the pelecypods, did not assume great numbers until the decline of the brachiopods at the end of the Paleozoic.

One of the typical gastropods of the Ordovician is shown here (Fig. 40). This was a large coiled snail, not unlike those of present seas. In some places it occurs in large numbers. The specimen figured came from Tennessee near Knoxville, although this or related gastropods are fairly common in Ordovician rock of Ohio, Kentucky, New York, Vermont, and Quebec.

Fig. 40. Gastropod of Ordovician age.

By the beginning of the Mesozoic, snails had increased greatly in numbers and formed a large percentage of the sea life of that era. By the beginning of Cretaceous time many of the genera of snails, as well as other mollusks, were identical with, or closely related to, those of present seas. If one collects fossil gastropods from Cretaceous localities such as Coon Creek, Tennessee, Eufaula, Alabama, Cream Ridge, New Jersey, or from many other areas covered by the Cretaceous sea, he will see close resemblances between these fossils and certain modern sea shells.

Figures 41, 42, 43 illustrate typical Cretaceous gastropods. Those of the Cenozoic Era are even more similar to present forms.

Cephalopoda is represented today by the squid, the octopus, the pearly nautilus and a few lesser-known forms. Although not too conspicuous in the seas today, their ancestors played important roles in the marine life of the past.

Fossil cephalopods are divided into three groups (orders) comprising the nautiloids, the ammonites and the coeloids. Let us mention a few of the characteristics of each.

Although some nautiloids today contain only a very thin shell, or no shell at all, their ancestors of the past, at least those preserved in the fossil record, all possessed conspicuous shells. The nautiloid shell may be straight, coiled, or partly straight and partly coiled. Judging from what we know of the contemporary nautilus, the animal lived in only the outermost compartment or chamber of the shell. The body was roughly oblong and contained a distinct head with well-marked eyes and tentacles. The shell of the animal is divided into a series of *chambers* or *camerae* which are separated from each other by

Fig. 41.

Fig. 42.

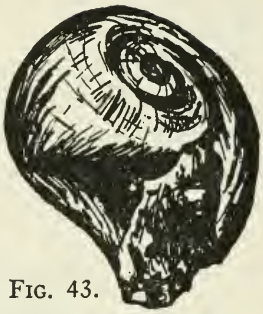


Fig. 43.

Fossil gastropods of Cretaceous age: (41, 42) *Anchura*, (43) *Gyrodes*.

partitions known as septae. The lines formed by the union of the septae and the shell are known as suture lines, and it is the design and complexity of the suture lines that are used for the classification of nautiloids. As the nautiloid grows and develops new chambers, the animal moves forward always occupying the outermost chamber. The abandoned chambers are frequently filled with gas and help to keep the animals afloat when swimming.

Fig. 44. Fossil *Nautilus* of Eocene age.

The nautiloid shell is calcareous and is usually lined with mother-of-pearl — hence the common name of one of the modern forms, "pearly nautilus."

The nautiloids made their first appearance in the late Cambrian or the early Ordovician and were fairly abundant throughout the Paleozoic Era. They decreased in numbers during the Mesozoic, probably because of the abundance of the ammonites, and have continued in small numbers to the present. Today

there are only three living species of the single genus *(Nautilus)*.

One of the most characteristic nautiloids of the Paleozoic is a form known as *Orthoceras*. These had long straight shells with simple sutures and were especially common in the Ordovician. They varied in length from a few inches to enormous creatures fifteen feet long.

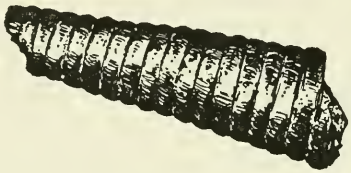


FIG. 45. Straight nautiloid, *Orthoceras*, of Ordovician age.

The ammonites probably developed from the nautiloids and differ from them mainly by having very complex suture lines. Like the nautiloids they may be straight, coiled, or partly straight and partly coiled. The ammonites first appeared in the late Silurian and became very numerous during the Mesozoic Era. They died out rather suddenly at the end of the Mesozoic (Cretaceous) and are not known from any younger rocks.

Ammonites are especially abundant in Jurassic and Cretaceous rocks. Pyritized remains of these creatures are frequently found in certain Jurassic rocks of Germany and elsewhere. In America they are more characteristic of the Cretaceous rocks mainly because of the widespread distribution of rocks of that age in this continent. Some of the Cretaceous ammonites were very large, one from Montana *(Parapuzosia)* reaching a diameter of over three feet. Some dozen or more species are known from the Cretaceous deposits of the Atlantic and Gulf Coastal Plain with a somewhat larger number being known from the Rocky Mountain states (Montana and Wyoming). Figure 46 shows a characteristic coiled ammonite of the Cre-

taceous, broken away to show the suture lines, not always visible on fossil specimens.

FIG. 46. Ammonite showing complex suture lines.

The Coeloidea include the squid and octopus as well as a few other lesser-known forms. They differ from the other cephalopods mainly in having either no shell, an internal shell, or one that is greatly reduced.

The fossil record of this group is not very conspicuous, the only one of any importance being the belemnite. This animal which may be regarded as a remote ancestor of the squid, made its first appearance during the Triassic and was very abundant throughout the rest of the Mesozoic Era. Little is known about this animal except for its internal skeleton or *pen* which sometimes occurs in great numbers in deposits of Jurassic or Cretaceous age. This pen was secreted by the animal and became embedded in the body as the animal grew. In a few cases remains of the tentacles or other soft parts of the animal have been found in the fossil state, but in almost all cases the pen is all that remains. But there are enough characteristics of the pen to enable paleontologists to recognize the species on it alone. Thus, the species and varieties of belemnites are often valuable as index fossils of specific Jurassic and Cretaceous formations.

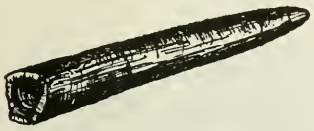


FIG. 47. Pen of Cretaceous Belemnite *(Belemnitella)*.

ARTHROPODA (Trilobites, Crabs, Insects, etc.)

This phylum probably contains the largest number of living species, mainly because of the great abundance of insects. It

is a diverse phylum made up of some six or more classes and numerous orders.

One of the most interesting of all invertebrate fossils is the trilobite, an animal which was very conspicuous in the seas of the Paleozoic Era and then died out at the end of the Permian period. It was one of the characteristic forms of several geological periods and its fossils today are much sought after by both professional and amateur paleontologists.

The animal is made up of three lobes, which extend along most of its length. The body also is composed of three parts or regions, the *head, thorax,* and *abdomen.* These vary in relative length according to the genus and species.

The head contained the cheeks, antennae and two well-developed compound eyes. The thorax was made up of a series of segments, varying from two to twenty-nine, to which were attached the jointed legs (usually lost in fossils) which were used for either crawling or swimming. The abdomen was covered by a caudal shield or pygidium with the segments fused

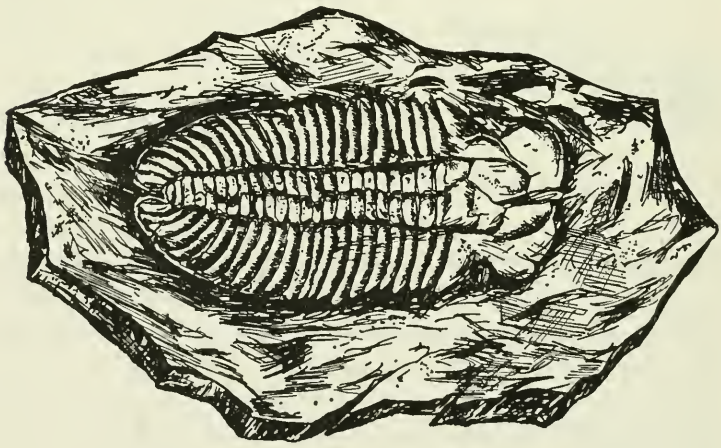


Fig. 48. Trilobite in Cambrian shale from British Columbia.

together. These features and many others have been used by the trilobite specialist to recognize some 130 families, 800 genera and 3,000 species of trilobites.

Trilobites vary in size from some Cambrian species less than ¼ inch in length to giants such as the Cambrian *Paradoxodes,* and the Ordovician *Isotelus gigas,* which were about 15 to 18 inches in length, and the giant of all trilobites, the Devonian *Terataspis grandis* which reached a length of 27 inches. Trilobites formed about 50 per cent of the life of the Cambrian, then slowly decreased in number until the end of the Devonian, and then were very inconspicuous throughout the remainder of the Paleozoic until they became extinct at the end of the Permian.

Although trilobites were numerous in Cambrian seas, it is not always easy to find them in the rocks. Many of them were small and fragile and became badly broken or crushed during preservation. Furthermore, many Cambrian rocks have been subjected to metamorphism and other changes, making it difficult to recognize these fossils. On the other hand, certain Cambrian rocks are noted for their very well preserved trilobite fossils.

Fig. 49. Coiled Devonian Trilobite, *Calymene.*

While Ordovician rocks have yielded some good examples of trilobites, it is the Silurian and Devonian formations that are probably the most favored for the trilobite collector.

Other arthropods occasionally found as fossils include the crabs, lobsters, barnacles, myriopods, insects and arachnids (spiders and their allies). While crab and barnacle plates are abundant in some fossil localities, they are not likely to be found by the average collector. Myriopods, insects and arachnids are even more rare as fossils.

FIG. 50. Fossil lobster or crawfish, *Hoploparia,* from the Cretaceous of New Jersey.

During the Age of Coal (Carboniferous) there were some very large dragonflies with wingspread up to three feet, but to date their fossils have only been found in France and Belgium. In America, fossil insects are largely restricted to a few species generally of archaic type found at Mason Creek, Illinois, Pottsville, Pennsylvania, and a few other places. Among the places most suitable for the preser-

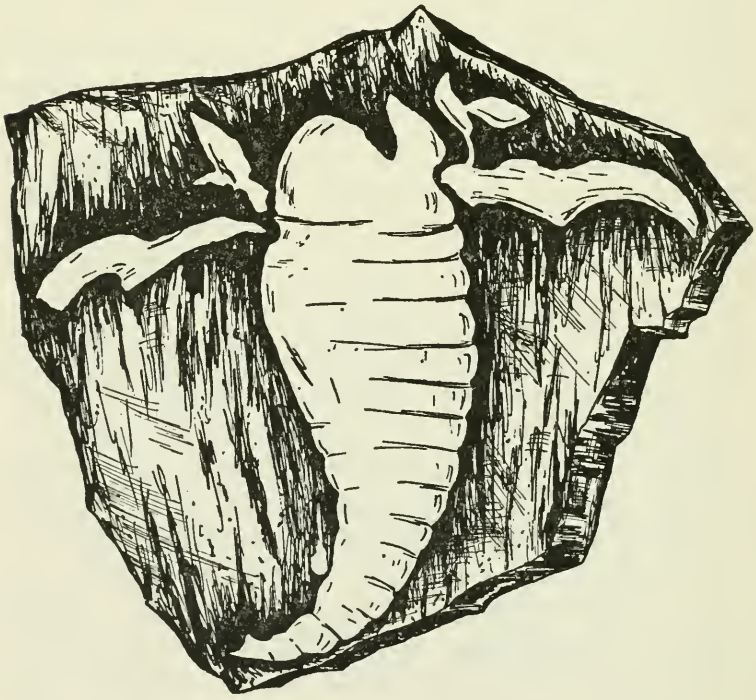


FIG. 51. Eurypterid, or Sea Scorpion, from the Silurian at Buffalo, N.Y.

vation of fossil insects are deposits of amber. Although the best-known supplies of amber come from the Baltic Coast of Europe and Zanzibar in East Africa, a few such deposits are known from North America, for example in Manitoba (Cretaceous age).

Among the arachnids, perhaps the most interesting animals to a paleontologist, is the king crab or horseshoe crab *(Limulus)*. This is sometimes spoken of as a "living fossil" because it has remained almost unchanged ever since the Paleozoic Era.

A related form, although entirely extinct, is the sea scorpion or eurypterid. These were aquatic arachnids, generally of moderate size, although a few such as *Pterygotus buffaloensis*, attained a length of nine feet. Although they are known to have lived from the late Cambrian to Pennsylvanian time, they are especially characteristic of the Silurian. Some of the best-known specimens have come from the Bennett Quarry in Buffalo, New York, now filled with water. The eurypterids at first were marine animals, but by Pennsylvanian time they had migrated into brackish or fresh water and were generally associated with a fresh-water assemblage.

6

Fossil Vertebrates

THE PHYLUM Chordata includes the familiar vertebrates generally grouped into the fish, amphibians, birds, reptiles and mammals. Although a study of fossil vertebrates forms a very important branch of Paleontology, these fossils with certain exceptions are much less likely to be found by the amateur collector and therefore will be discussed in much less detail than the invertebrate specimens.

CHORDATA

Fish

Perfect fossil fish are not very common, although some splendid specimens are known from the Green River shales of Utah and Wyoming (Eocene), the shales and sandstones along the Bay of Chaleur in the Gaspé region of eastern Canada (Devonian), near Cleveland, Ohio (Devonian), various shales of the Newark series in Pennsylvania, Connecticut, New Jersey and Virginia (Triassic) and in concretions at another place called Green River, near Ottawa, Ontario (Pleistocene).

Although complete fossil fish are relatively rare, the teeth of certain fish, especially the sharks, are exceedingly abundant in some localities. These generally are all that remains of the sharks that lived in ancient seas, the rest of the skeletons being softer than ordinary bone and less likely to be preserved. Shark teeth can be found in many formations from Devonian

to Pleistocene, but are most abundant in deposits of Cretaceous age or younger. For example, many fine specimens have been found in Cretaceous and Eocene greensands of New Jersey and the Tertiary sands of Maryland, the Carolinas, Georgia, and Florida. Among the localities most noted for their fossil shark teeth are the Calvert Cliffs of Maryland and the deposits along the Ashley River near Charleston, South Carolina.

Other fossil fish remains include the teeth of rays, spines of sharks and their relatives, individual vertebrae, as well as scales of numerous species.

FIG. 52. Two shark teeth of Miocene age.

Sometimes, but not always, sharks can be identified by their teeth, generally by comparison with skeletons of living sharks. As a general rule it has been determined that one inch of tooth is equivalent to ten feet of shark. Thus a three-inch tooth is thought to have come from a thirty-foot shark. This formula does not always apply, for a single shark will have teeth of various sizes. In general, a large fully grown tooth should be measured when applying this formula.

AMPHIBIANS

Relatively little is known about fossil amphibians, most of the fossils being fragmentary and not very well preserved. Some of the best-known examples have come from Greenland. This is a group of fossils not likely to be encountered by the beginning paleontologist.

Reptiles

The one type of ancient animal most frequently associated with the word "fossil" is the dinosaur. These large reptiles lived during the Mesozoic Era, giving it the popular name, Age of Reptiles. These animals varied in size from some small forms, not much bigger than an ostrich, to the great *Brontosaurus,* which reached as much as seventy feet in length.

The dinosaurs of the Triassic were generally small, although some footprints found in the Connecticut River Valley near South Hadley, Massachusetts, suggest that there were also some rather large individuals during this period. The most extensive series of Triassic dinosaurs in America has come from New Mexico. Although footprints are fairly numerous in the Triassic rocks of eastern United States, the actual dinosaur remains are very rare, probably the best one being a six-foot individual known as *Yaleosaurus* (the Yale Reptile) found near New Haven, Connecticut.

By Jurassic time the dinosaurs had reached great size. Some of the more spectacular Jurassic dinosaurs such as *Brontosaurus, Stegasaurus,* and *Diplodocus* have been pictured in many restorations and murals. In fact, life-sized models of some of these as well as other dinosaurs are on display in various parks, for example at Rapid City, South Dakota, and Calgary, Canada. Dinosaur National Park in the Uinta Mountains of Utah is also famous for its dinosaur fossils. The Jurassic dinosaurs are most abundant in the Morrison formation in Montana, Colorado, and Alberta. None are known from eastern United States.

The Cretaceous dinosaurs had lost little if any of their grandeur, and some of these forms such as *Tyrannosaurus, Triceratops,* and the Duckbills *(Hadrosaurus,* and *Trachodon)* are very familiar to many because of their restorations. Although the Cretaceous dinosaurs like those of the Jurassic

Fig. 53. Duck Bill Dinosaur, *Hadrosaurus,* of Cretaceous age.

are more characteristic of western United States, it is interesting to note that the first reasonably complete skeleton of a dinosaur was a Duckbill *(Hadrasaurus)* found in 1858 at Haddonfield, New Jersey. The best examples of Cretaceous dinosaurs have come from the western states, especially Montana. Eastern records include, in addition to the Haddonfield individual, other fragmentary remains from New Jersey, Maryland and North Carolina.

Not all large reptiles of the Mesozoic were dinosaurs. Other extinct inhabitants of the Age of Reptiles include the crocodile-like phytosaur which lived only during the Triassic, the long-necked plesiosaurs looking not unlike some versions of a "sea monster," as well as other aquatic reptiles such as the ichthyosaur and mosasaur. The reptiles also took to the air during this era with such fantastic forms as the pterosaurs, truly flying dragons.

Why did the dinosaurs and other large reptiles of the Mesozoic Era become extinct? This is a question often asked and for which there is no answer that is entirely satisfactory to all. Perhaps they became so large that they had difficulty getting around. It is known that many groups of animals tend to become larger as individuals during their racial history (for example, the horse, elephant, etc.), and it is possible that the dinosaurs just got too big for themselves.

The dinosaurs had very small brains, and it may well be that they just could not compete with the more intelligent mammals which were beginning to make their appearance. And speaking of mammals, it has often been suggested that they were the main cause of the extinction of these large reptiles. It is difficult to understand how these small Cretaceous mammals (rarely more than a few feet in length) could exterminate the immense Cretaceous reptiles, but they were faster and thus might have been able to defeat the larger forms in the constant quest for food. A more plausible explanation is that

the primitive mammals fed on the eggs of the dinosaurs, for most dinosaurs, like other reptiles, laid eggs. Other possible suggestions include changes in climate, disease, and racial senescence—that is, a natural dying out of the race.

The disappearance of these large reptiles at the end of the Cretaceous period probably can best be explained by a combination of these various factors. At any rate, no one has yet found a Paleocene dinosaur.

It must be remembered that not all large reptiles died out. The Age of Reptiles also include large crocodiles, turtles, and snakes and, as we all know, those forms survived the Mesozoic and are still with us today. How were they able to survive the "great dying" while their cousins, the dinosaurs, mosasaurs, etc., became extinct? We cannot yet answer that question.

Although reptiles are the most spectacular of all fossils, it is not very likely that the beginning or amateur paleontologist will have much luck finding any. Of course, it is always possible that such fossils can be found, and it would certainly be worth while looking for them in Triassic, Jurassic, or Cretaceous sediments provided that one's hopes are not too high, for the great majority of fossil-reptile hunters are doomed to disappointment. One other point about dinosaur hunting should be mentioned at this time. In case a good fossil reptile is found, the discoverer should notify a professional geologist so that he can advise or help in its removal. Most fossil vertebrates are very difficult to excavate. The bones may be soft and may require careful treatment with plaster and shellac before they can be removed. Many fine specimens have been destroyed by overzealous enthusiasm. It is better to play safe and get all the advice possible than to have a valuable specimen lost or damaged. Many museums have trained personnel who are familiar with all the problems of excavation, and will gladly give all the advice and help needed. Then, if the specimen really is worth while, the finder should consider giving it to a

museum, for it would be better to have it displayed than stored away in an attic or cellar, for dinosaurs rarely make good living-room decorations.

While the chances of finding a complete dinosaur or other large reptile are rather small, it is quite possible to find some fragments of fossil reptiles. By knowing in what formations and areas dinosaurs have been found, the search can be restricted and it may be possible to find some teeth, vertebrae or other bones. Mosasaur teeth are not uncommon in some formations, for example in the Cretaceous greensand of New Jersey. Fragments of turtles or crocodiles are also found in many places, for example in the Coastal Plain of Alabama and the Badlands of South Dakota.

Birds

The chances of bird bones being preserved as fossils are exceedingly small, so it is very unlikely that the novice paleontologist will have any of these specimens in his collection.

Mammals

Like the fossil reptiles, mammal remains are generally difficult to remove and will seldom constitute the main part of the amateur's collection. Furthermore, the space required for displaying fossil mammals is generally prohibitive. Not many young paleontologists live in homes large enough to permit the display of fossil skeletons of mammoths, mastodons and other large mammals.

Certain regions are noted for their fine fossil mammals, and here they may be collected with relatively little difficulty. Such places include the Badlands of South Dakota, as well as parts of Nebraska and Wyoming. It should be noted, however, that a permit is required in many of these places before fossil vertebrates can be removed.

If a collector wants to include fossil mammals, it might be

well to limit the material to the bones or teeth of small mammals, or perhaps a few larger teeth such as those of the mastodon or mammoth.

The mastodon and mammoth lived in North America during the Pleistocene and their remains are known from a large number of places. While complete skeletons are not often found, their teeth are fairly common in some places, and would make very nice additions to any fossil collection.

During recent years a number of interesting bones and teeth of Pleistocene mammals have been found on the beaches of New Jersey, South Carolina, and elsewhere. A few other such specimens have been dredged by fishermen from the bottom

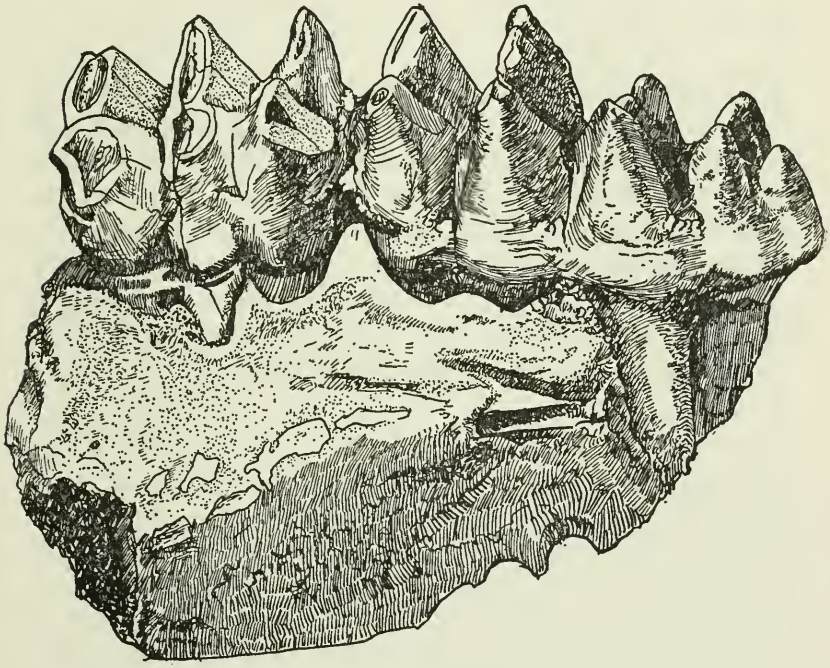


FIG. 54. Tooth of Pleistocene Mastodon.

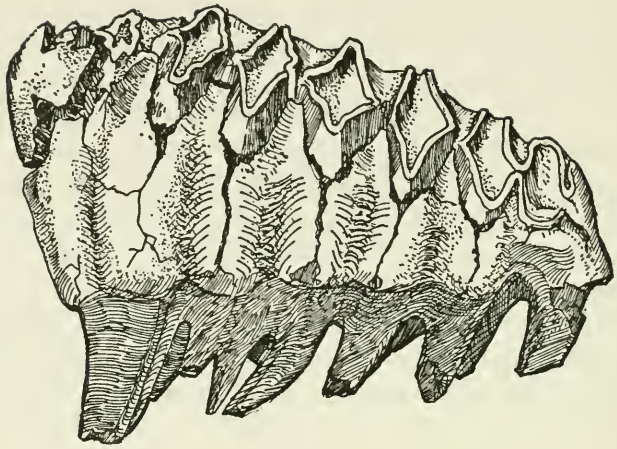


FIG. 55. Tooth of Pleistocene Mammoth.

of the ocean some twenty-five miles or more off the coast. It has been suggested that these are the remains of animals that lived during the Pleistocene epoch when the land extended many miles beyond the present strand line. (Considerable water was removed from the sea to form the glaciers, causing sea level to fall some 300 feet, with a consequent moving of the shore line far out to sea.) Among the mammal remains that have been collected from the Atlantic beaches are those of the mammoth, mastodon, sloth, walrus, and tapir.

7

Fossil Plants

IT is true that the great majority of fossils are of animals rather than plants; however, there are many parts of the country, for example the coal fields, where fossil plants are abundant.

Plants, like animals, are divided into phyla and subdivided into classes, orders and families. Not all phyla are equally well represented in the fossil state and some are so poorly preserved that they would be overlooked by all except the highly trained specialist.

ALGAE

Primitive plants were confined to the seas and may be thought of as remote ancestors of modern seaweeds. It was probably not until the Silurian that plants began their move from the sea onto land. Judging by the fossil record, the plant life of the pre-Cambrian, Cambrian and Ordovician was limited to algae. While these were among the most primitive of plants, they were not all small. Some grew into large colonies and like some of the contemporary algae of tropic seas secreted layers of calcium carbonate. While the cells themselves have long since disappeared, the limy layers which they secreted sometimes remain as fossils. Some of these lime-secreting algae, known as Cryptozoa, grew in large reefs or colonies. A few of them look like large heads of cabbage and are sometimes called "fossil cabbages."

TABLE OF PLANTS

CLASSIFICATION	ILLUSTRATIONS
ANGIOSPERMS "FLOWERING PLANTS"	
"CONIFERS"	
"CYCADS"	
"FERNS"	
LEPIDOPHYTA	
ARTHROPHYTA	
PSILOPSIDA	
BRYOPHYTA (MOSSES)	
FUNGI	
ALGAE	

FIG. 56. Pictorial table showing the main divisions of the classification of plants.

Cryptozoa are among the oldest of all fossils having been found in the pre-Cambrian rocks of Montana, Michigan, Canada and Mexico. They are also present in many Cambrian and Ordovician limestones in different parts of the country. Probably the best-known example is from near Saratoga Springs, New York, where an unusually fine colony is preserved in a small state park.

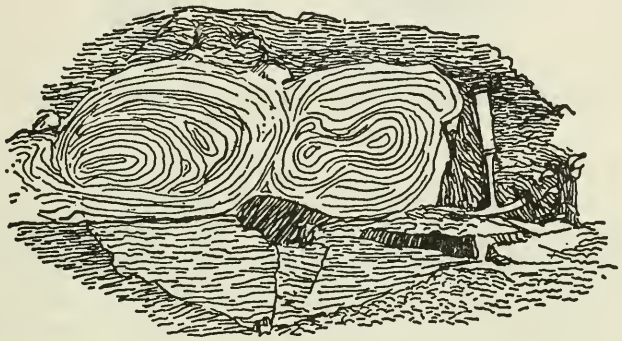


Fig. 57. Fossil Algae or Cryptozoa of Cambrian age.

Less distinct remains of fossil algae are present in many rocks of all ages. Some of these are impressions that somewhat resemble the living *Fucus* or rock weed of our Atlantic Coast and therefore are known by the popular name "fucoid." These fucoids are very indistinct and are of little value to the paleontologist. Sometimes it is said that if a paleontologist finds a vague plant-like impression in a rock and does not know what it is, he calls it a fucoid.

Some microscopic algae, known as diatoms, are present in deposits of various ages. In California they are known from Cretaceous rocks and younger, while on the Atlantic Coast they are known only from the Miocene to the Recent. They are often used as index fossils both on the surface and in samples obtained from borings for deep wells.

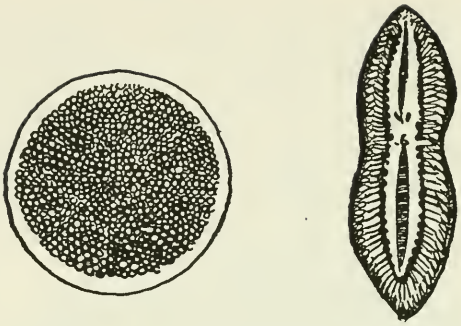


Fig. 58. Diatoms of Miocene age (greatly enlarged).

OTHER PRIMITIVE PLANTS

Among these might be mentioned the Fungi (mushrooms, toadstools and the like), and the Bryophytes (mosses and liverworts). Both groups are so rare in the fossil record that it is almost certain that they would not be found by the average collector.

PSILOPSIDA

The Psilopsida comprises a group of plants known by only three genera, two from the Devonian and one from the present. While it is exceedingly unlikely that any fossils of this phylum will be found by the average collector, it might be well for us to mention them briefly because of their great importance in the evolutionary development of the land plants.

The most familiar fossils of this group are known from two widely separated localities, one in the Gaspé region of Canada and the others from Rhynia in Scotland; both are of the Devonian age. The plants had a woody stem about half an inch in diameter and leafless branches rising to the height of about two feet. The name "Leafless Tree" is sometimes given to this group of plants. They are very primitive and are thought

of as being the possible ancestor of the ferns and other land plants.

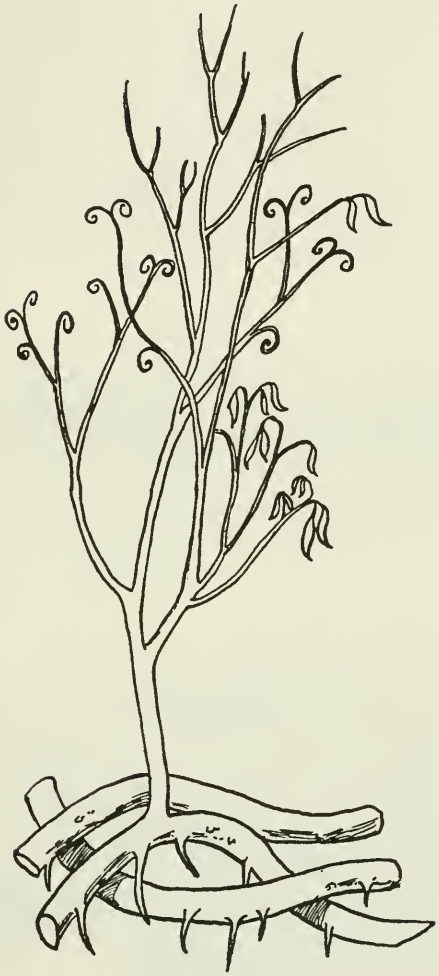


FIG. 59. Restoration of Leafless Tree *(Psilophyton)* of Devonian age.

ARTHROPHYTA (Horsetails, Calamites)

This phylum is often called by the name Sphenopsida. The best-known fossil representative of the group is the genus *Calamites,* which flourished in the coal swamps of Carboniferous time. Some of these calamites reached the size of forest trees and were as much as 100 feet in height. They are characterized by their jointed stalks with clusters of leaves, known as *annularia,* at the nodes. The annularia were frequently detached from the stalk and for a long time paleobotanists did not realize what plants they had come from.

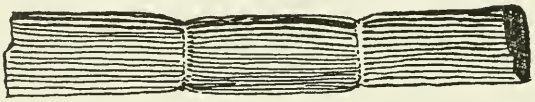


Fig. 60. Portion of stem of *Calamites* of the Age of Coal.

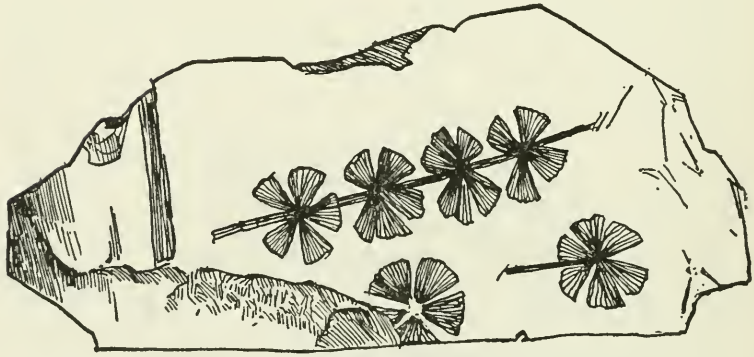


Fig. 61. Leaf cluster or *Annularia* from the Coal Swamps.

The calamites first appeared in the Devonian and then reached the peak of their development in the Carboniferous (Pennsylvanian); they may be looked for in coal deposits in Pennsylvania, West Virginia, Ohio, Nova Scotia and elsewhere. They had begun to decrease in size and number by Permian time and from then on were known only by relatively small individuals. The present-day *Equisetum* or horse tail is a descendant of this once important group of plants.

LEPIDOPHYTA (Scale Trees)

This is another group of plants once numerous and majestic, now represented only by a few small plants known as club mosses.

The group made its first appearance during the Silurian or Devonian, and like the calamites reached its climax during the coal swamps of the Carboniferous. Some of these plants were six feet in diameter and were as much as two hundred feet in height. The leaves of the trees were closely attached to the trunk; when the leaves fell off, permanent scars were left on the trunk, thus giving the name scale tree to the plants. Large trunks or broken pieces of bark of scale trees are frequently

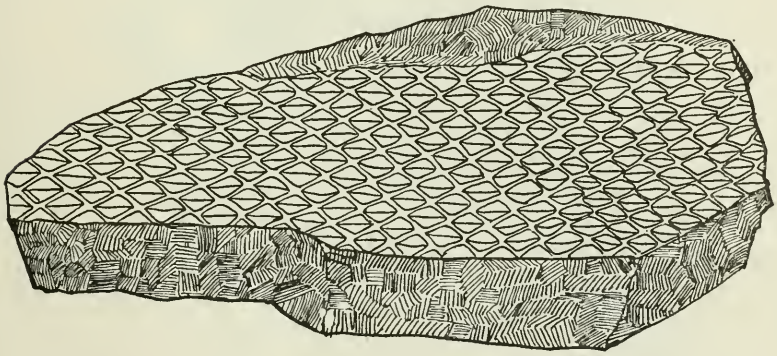


FIG. 62. Portion of the trunk of a Scale Tree *(Lepidodendron)* from the Coal Swamps.

found in coal deposits; in fact they are the most common fossils of the coal fields of Pennsylvania, and many other regions.

Because of the resemblance of the scaly bark of these plants to the skin of a reptile, they are frequently misidentified as the skin of a crocodile, alligator or some other reptile.

The most common member of this phylum is the genus *Lepidodendron,* shown above.

FERNS

The ferns fall into two phyla—the Pteridophyta or true ferns and the Pteridospermatophyta or seed ferns. Since they are

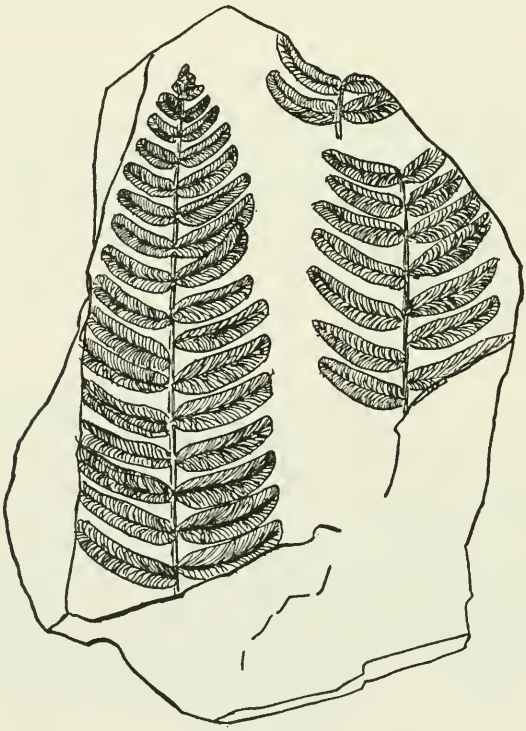


Fig. 63. Fossil fern from Pennsylvanian shales near Pottsville, Pa.

very difficult to tell apart except when found with their fruiting bodies attached, they will be discussed as a unit.

The ferns made their appearance in the Devonian, and like the scale trees and calamites reached gigantic proportions during the Carboniferous, some of the true ferns of that period reaching as much as fifty feet in height.

True ferns reproduce by spores which are attached to the underside of the branches. Seed ferns reproduce by seeds. The

FIG. 64. Cycad.

true ferns have persisted to the present day, while the seed ferns died out at the end of the Permian.

CYCADS

These plants first appeared during the Devonian and were present, but not abundant, during the Carboniferous. They reached their climax during the Jurassic, sometimes giving the name Age of Cycads to that period. The cycad is characterized by a trunk crowned by a whorl of leaves. A familiar cycad of the present tropics is the sago palm.

CONIFERS

This group includes the cone-bearing trees such as the pine, spruce, fir and the like. They were represented in the Paleozoic by some tall slender trees rather unlike the modern conifers. Conifers closely related to those of today made their first

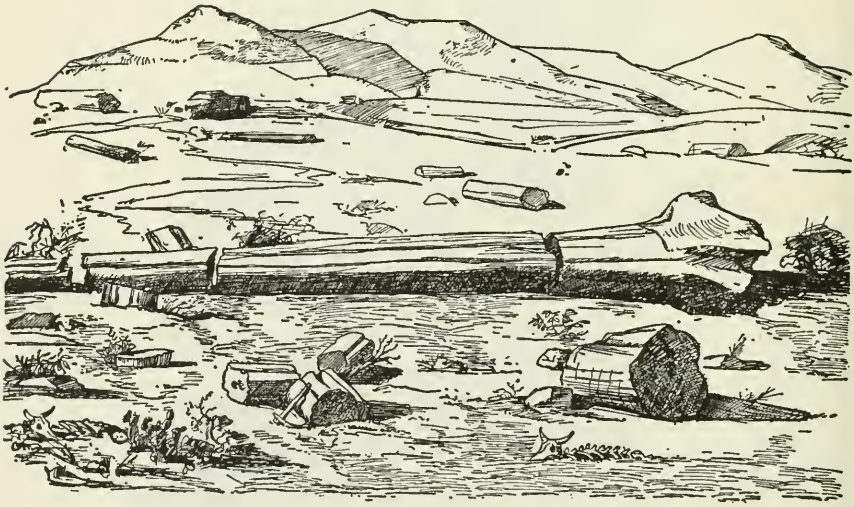


Fig. 65. Petrified Forest of Arizona showing trunks of Triassic conifers.

appearance in the Triassic. Fossil cones of the pine and other conifers are frequently found in deposits of Triassic and Cretaceous age. Many of the logs of the Petrified Forest in Arizona are silicified replacements of conifers that lived in that region during the Triassic time.

ANGIOSPERMS

These are the flowering plants and include most of the familiar plants of today. They made their first appearance during the Cretaceous and have been the dominant plants ever since.

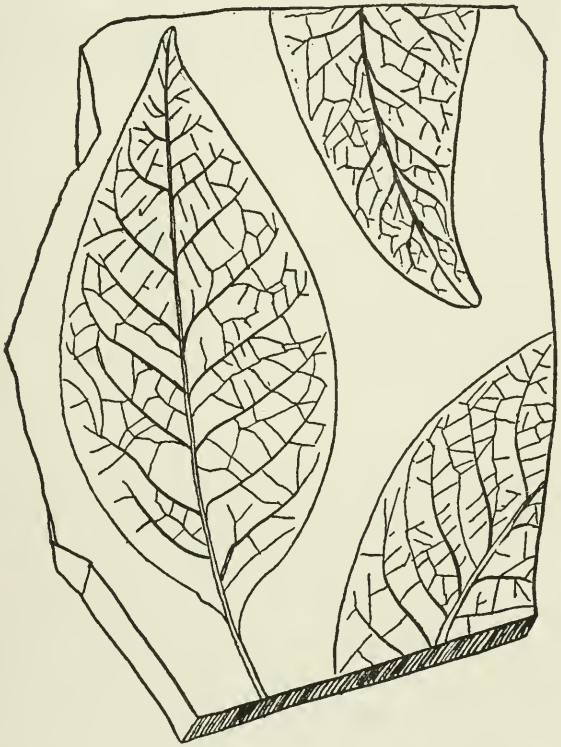


FIG. 66. Leaves of *Magnolia* of Cretaceous age.

Leaves, stems, fruits and even flowers are known from nonmarine rocks of the Cretaceous age and younger. Some of the best-known fossil angiosperms have come from Montana, South Dakota, and Colorado.

Not only may the plants themselves be preserved in the rocks, but also pollen grains are frequently common, especially in formations of Pleistocene. In fact a great deal of the details of the climatic changes of the Pleistocene has been worked out by a study of fossil pollen. While these studies have been most actively pursued in Europe, strides in this phase of Paleontology—called Palynology—have recently been taken in the United States. Special microscopic techniques are required for these studies, and are outside the scope of the average paleontologist.

8

Sedimentary Rocks

MOST PEOPLE think of rocks as hard, solid material which makes up a large part of the surface of the earth. Geologists are not entirely agreed as to what constitutes a rock. Some maintain that rocks must be hard and solid, while others use the term to cover all materials which make up the crust of the earth. In the former case, sand, clay and silt would not be classed as rocks, while in the latter they would be so regarded. In fact, recently legal action was taken to decide whether or not certain sand was a rock. If so, the owner of the quarry or pit containing it would be entitled to certain tax deductions not available if the product were not classified as a rock. The latest tax laws have been reworded to avoid this confusion.

To avoid any misunderstanding, let us decide at once that the term rock refers to all material comprising the earth's shell. This would include soft or unconsolidated materials such as sand, clay and silt, as well as hard or consolidated materials such as sandstone, limestone and granite.

The terms rocks and mineral are sometimes used interchangeably by the new collector, but to an earth scientist they are quite distinct and should never be confused. Minerals are the fundamental units which are combined to make up rocks. While a mineral has a definite chemical composition or formula (with a limited variation), a rock, being composed of minerals

in varying amounts, has no fixed formula and may vary widely depending upon the percentages of the different mineral constituents. Thus a sandstone may be composed entirely or almost entirely of quartz, or this mineral may be mixed with mica, feldspar, kaoline or other minerals. It is a sandstone only by virtue of the size of the grains making up the rock and not because of the mineral constituents.

In a previous chapter we have learned some of the important groups of fossils, and how a study of these fossils is of help in unraveling the geological story of the earth. A knowledge of the different kinds of rocks is also essential if we are to understand the main events that have taken place in the geologic past. A geologist can often interpret as much of the past climate and environment from a detailed study of the rocks and their minerals as he can from the fossils, and in many cases he has no fossils to work with. From a practical point of view, the recognition of the different kinds of rocks will be of value in a search for specific minerals or ores. As will be seen later, certain minerals are frequently associated with definite kinds of rocks.

Let us briefly point out the characteristics of some of the more common rocks in the sedimentary group.

SEDIMENTARY ROCKS

Most of the rocks of this class have been formed by the breaking down and deposition of pre-existing rocks. A few were formed by chemical action or by the work of marine organisms. The great majority of sedimentary rocks were deposited beneath the sea. However, a few were formed under fresh water or on land. As the name implies, these rocks were formed as sediments and generally occur in layers or strata.

Since we have decided that our interpretation of the word "rock" does not require the material to be hard or consolidated,

let us first divide the sedimentary rocks into two groups, those that are soft or unconsolidated and those that are hard or consolidated.

UNCONSOLIDATED

Clay is made up of particles so small that they cannot be seen with the naked eye; in fact, they are less than 1/256 mm. in diameter. In addition to the smaller size of the particles, clays differ from sands in that they usually cohere or stick together when wet. Clay is generally largely composed of the mineral kaolin (see page 140). While many clays are wet and sticky, water does not readily pass through them.

Clays can be of almost any color, depending upon the chemical composition and the presence of impurities. The chief use of clay is in the making of bricks, although recently pure kaolin has been used in the manufacture of coated paper, rubber and other products.

Silt is made up of particles somewhat larger than those of a clay. Specifically, silt grains vary from 1/256 mm. to 1/16 mm. With a little practice silts can be distinguished from clays by their slightly gritty feel, owing to the larger size of the grains.

Sand is an unconsolidated sediment made up of particles less than 2 mm. in diameter and more than 1/16 mm. Qualifying adjectives such as fine, medium and coarse are frequently used in describing a sand. Although most sand is composed largely of the mineral quartz, there are sands made up predominately or entirely of such materials as gypsum (as in the White Sands Monument of New Mexico), calcium carbonate (as in the coral sands of Bermuda and the Bahamas) and glauconite (as in the greens and deposits of New Jersey and elsewhere). Pure quartz is frequently used in the manufacture of glass, while almost any sand can be used for concrete or building aggregate. The location of buried sand deposits is important to the eco-

nomic geologist because sands form the best reservoirs for oil or ground water.

Gravel is an unconsolidated sediment made up of pebbles larger than 2 mm. in diameter.

Limy Ooze is a rarely seen type of sediment or rock which is mentioned here mainly because it becomes consolidated into limestone. It is composed of fragments of shells and microscopic lime-secreting organisms and is accumulating today in many tropical seas.

Marl is frequently confusing to even the professional geologist because the term has so many uses. In some places the term is used for the porous mass of shells or calcareous (limy) algae found on the bottom of certain lakes. Abundant algal marl is known from Pyramid Lake, Nevada, while good examples of fresh-water shell marl can be seen at the bottom of what are now extinct glacial lakes in Ohio, New Jersey, New York and elsewhere.

Another use of the term marl is for a mixture of shell fragments and sand or clay. This is the most common use along the Atlantic coastal plain where marl was formerly extensively dug for fertilizer.

A third use of the term, generally restricted to New Jersey is for the glauconitic sands which are common in certain Cretaceous and Eocene formations of that state. Greensand marl can also be used as a fertilizer because of the presence of potassium; it is also used as a water softener.

CONSOLIDATED

Shale is silt or clay that has become consolidated. It usually occurs in thin beds which peel off when exposed to the air. The color of the shale is generally that of the original clay or silt.

Qualifying adjectives are frequently used in describing

shales. For instance an arenaceous shale refers to a shale with an abundance of sand grains; in other words, it is a sandy shale. A calcareous shale is a mixture of shale and limestone while a carbonaceous shale is one which contains an abundance of organic material.

Oil Shale is one variety of shale that deserves special mention. It contains great quantities of petroleum which cannot be obtained by ordinary methods of drilling. The oil is locked in the rock and can only be released by a complicated process of distillation. At present this is too expensive to compete with the ordinary methods of drilling, but in time it may surplant the more conventional methods of obtaining oil. Great reserves of oil shale exist in Colorado.

Sandstone is consolidated sand, the sand grains having been cemented together to form a hard mass. This process of solidification may have been brought about by one of several causes. Usually some cementing agent, such as silica, calcium carbonate or iron (limonite), has been added by the circulating ground water.

As in the case of shale, there are numerous varieties of sandstone such as *calcareous* (lime), *argilaceous* (clay) and *ferruginous* (iron).

Arkose is a fairly coarse sandstone with an abundance of feldspar and is thought to have been formed by the disintegration of granite or some similar igneous rock. Arkose deposits generally suggest that the rock was laid down under rather arid conditions or at least in a terrestrial rather than marine environment.

Conglomerate is a consolidated gravel. The pebbles and the finer material, usually sand, which fill the interspaces are held together by some cementing agent. The pebbles are rounded and usually of quartz, although other materials such as flint and chert are also common in some conglomerates. In certain cases there is a sharp contrast in color between the pebbles

and the background. This kind of conglomerate is popularly known as a pudding stone and is abundant in various places, for example, at Mount Tom in Massachusetts.

Breccia differs from a conglomerate in that the pebbles are angular rather than rounded. Breccias are especially characteristic of lavas and material that has been transported by glacial ice.

Limestone is made up predominately of calcium carbonate (calcite) usually with very fine granular texture. The main source of the limestone is the limy ooze formed in the ocean by small organisms, plants and animals and by the accumulation of fragments of larger lime-secreting organisms. Some limestone, is thought to be precipitated directly from sea water, living animal or plant.

Most limestones were formed in the ocean, although there are some cases, for example in Wyoming and Florida, where the limestone is known to have accumulated in fresh-water lakes. Several varieties of limestone deserve attention.

Sometimes spoken of as shell rock, *coquina* is made up of fragments or complete specimens of small shells. It is a relatively soft rock which crumbles very easily. It is forming today in the shallow water off the Florida Coast; during the warm interglacial stages of the Pleistocene it formed as far north as North Carolina and even New York, judging by some fragments of this kind of rock found in the excavations for one of the tunnels under the Hudson River at New York City. Some coquina is quite hard and is used as a building stone. Fort Marion near St. Augustine, Florida, was constructed of coquina quarried from the nearby beach.

As the name, *coral limestone,* implies, this type of limestone is composed largely of the remains of ancient corals. It is forming today in most tropical waters and during various stages of the geologic past it formed great reefs in many of the inland seas. Since coral limestone forms now only under tropical or

subtropical conditions, its presence in Paleozoic or Mesozoic formations in the temperate or even Arctic regions strongly suggests times in the history of the earth when the climate was considerably warmer than at present. Coral limestone is abundant in the Silurian and Devonian formations of Illinois. It is also one of the main kinds of rocks found in the Florida Keys and on many of the islands of the West Indies.

Another type of limestone, *chalk,* made up largely of the remains of minute single-celled organisms known as Foraminifera (see p. 40). Chalk is usually white or gray and can be very massive as in the chalk cliffs along the English Channel. In fact, the abundance of chalk in certain deposits of Europe gave the name Cretaceous (from *creta* meaning chalk) to one of the major geological periods. Chalk is less abundant in North America than in Europe but is known from Cretaceous deposits in Alabama, near Selma, and in Austin, Texas. Chalk deposits frequently contain large concretions of flint (see p. 103).

The term *oolite* means "little eggs," and is used for a type of limestone consisting of small rounded particles resembling fish eggs. It is not known exactly how this rock forms, but in many cases it is probable that the calcium carbonate accumulates around a sand grain or shell fragment. Oolitic limestone can be seen in Pleistocene deposits of Florida, and in the Bahamas.

Although *stalactites and stalagmites* are not distinct types of limestone, they deserve special mention because of the widespread interest in cave exploration. Limestone is a very soluble rock and readily dissolves forming caves, karsts or sinkholes. (The latter two may be regarded as caves without a roof or where the roof has fallen in.) Not only does the ground water act to dissolve away the limestone forming the caves, but it also deposits calcium carbonate in the caves. This material assumes various shapes, the most frequent being the icicle-

like stalactites which hang from the roof and the stalagmites which grow upward from the floor of the cave. When these two meet they form a *column* or a *pillar*. The stalactite is usually wet to the touch because of the water trickling down from the roof of the cave. It is this water that carries the calcium which causes the stalactite to grow. Both stalactites and stalagmites are frequently coated with a fringe of calcite crystals.

Fig. 67. Limestone cave showing stalagmites and stalactites.

Caves noted for their beautiful limestone formations are widespread in the Shenandoah Valley of Virginia—for example, Luray, Endless Caverns, Grand Caverns—as well as in many other limestone areas of the country. Probably the most famous of all is Carlsbad Cavern in New Mexico which contains

stalactites up to 16 feet in diameter and 62 feet in height.

Even though *dolomite* is really a distinct type of rock rather than a variety of limestone, it is included here because of its close similarity to limestone and because of the fact that the two intergrade. A dolomite is distinguished from a limestone mainly by the presence of magnesium in addition to calcium. It is thus a calcium magnesium carbonate. The magnesium may have been introduced later by the replacement of calcium. The intermediate stage is called *dolomitic limestone*. Dolomite can easily be distinguished from limestone because it does not "fizz" with a weak solution of hydrochloric acid. (It does fizz when the acid is heated.) The term dolomite is used both for the rock and the mineral making up the pure rock. (See p. 150.)

Limestone has many uses, probably the most familiar being as a building stone, crushed stone for concrete or road building. It is also used as a flux for blast furnaces in the steel industry and it is frequently ground for the manufacture of "quicklime" and other products for the chemical and agricultural industry.

Certain limestones, especially when they contain sufficient clay or shale impurities, are ideal for the manufacture of cement. "Natural cement rock" occurs widely in the Lehigh Valley of Pennsylvania.

Chert and Flint: These are dense siliceous rocks that occur either in distinct layers or as lenses in other rocks, especially limestones. Although the names are frequently used synonymously, chert is generally regarded as light gray in color while flint is dark gray or black. The origin of chert and flint is rather complicated and not thoroughly understood. Some of it probably formed as a precipitation of colloidal silica directly in the sea, while other examples probably represent a later replacement. Both rocks are varieties of quartz, but they do not occur in crystals.

Chert which originally occurred as nodules in limestone

frequently is found today as pebbles, the limestone having worn away. If the limestone was fossiliferous, the chert pebbles may contain fragments of fossils or in some cases perfect specimens.

Jasper is a red or brown variety of chert, the color being caused by impurities of iron. Another variety of chert which is banded and highly ornamental is called agate.

Varieties of chert and flint were used by ancient men for the manufacture of tools, both in the Old World and the New.

Salt and Gypsum: The evaporation of sea water causes the deposition of salt. While the main constituent of sea water is sodium chlorite (halite), various other salts are also present and precipitate from the sea water. Salt is now obtained from deposits laid down by ancient seas that have now receded. The best-known salt deposits in America are in New York, Michigan, Ohio, Louisiana and Kansas. Gypsum (calcium sulphate) also precipitates from sea water and may occur with ordinary salt or separately. Beds of gypsum occur in western New York, near Grand Rapids, Michigan, as well as in various places in Kansas, Oklahoma, Texas, Oregon, South Dakota, Wyoming as well as in New Brunswick and Nova Scotia in Canada.

The uses of ordinary salt are obvious. Gypsum is the main ingredient of plaster (see p. 151).

Phosphate Rock: Phosphorous is, of course, one of the elements important to man. It is present in bones, teeth and other structures. In a few places there are beds of sedimentary rock containing sufficient quantities of phosphorous — in the form of phosphates — to make them a valuable source of fertilizer. The largest deposits of phosphate in the United States occur in Montana, Idaho and Wyoming. See the discussion of the phosphorous mineral apatite (page 149).

Coal: Under certain conditions, usually in swamps, decayed

plant material will form peat. In turn, this may be hardened to lignite or coal. Lignite and soft (bituminous) coal are generally classed as sedimentary rocks. Hard (anthracite) coal has been greatly altered by heat and pressure and is regarded as a metamorphic rock.

9

Igneous Rocks

THIS KIND of rock takes its name from the Latin *ignis* meaning fire. These rocks were formed by the deposition of hot liquid material known as magma from deep beneath the surface of the earth. In thinking of igneous rocks one probably thinks first of volcanoes with their lava and cinders. However, not all igneous rocks came from volcanoes. At many times during the geologic past hot, molten igneous rocks rose from deep within the earth into the overlying layers, but did not reach the surface of the land. They are now visible because the overlying rocks, usually softer than the igneous rocks, have eroded away exposing the intruding rocks on the surface of the ground, frequently in the form of hills or ridges. These are called *intrusive igneous rocks* and include such types as granite, basalt and diabase.

Extrusive igneous rocks are those that reached the surface of the earth either through volcanoes or by way of great fissures on the surface of the earth such as now occur in Iceland and once were numerous in the Columbia River Plateau, as well as in parts of Pennsylvania, New Jersey and Connecticut. Some of these igneous rocks are difficult to distinguish from those of the intrusive type and frequently can only be differentiated by careful microscopic examination. Among the more common types of extrusive igneous rocks are various kinds of lava, cinders and volcanic ash.

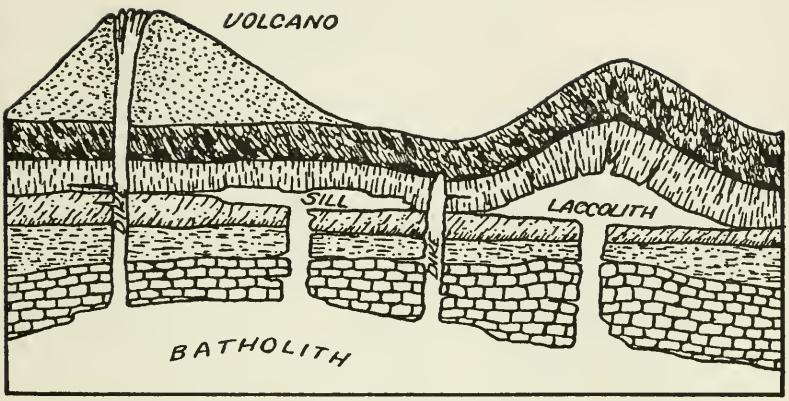


FIG. 68. Intrusive and extrusive igneous rocks.

Igneous rocks are much harder to identify than the sedimentaries. In fact, a detailed microscopic examination is frequently necessary before an exact determination can be made. However, there are a few types of igneous rocks that are widely distributed, which should not be too difficult for the beginning earth scientist to recognize.

In general, igneous rocks fall into two main groups according to their chemical composition: (1) the acidic (sometimes called silicic or felsic) which have a high silica content, are usually light in color and have a low specific gravity and (2) the basic rocks (sometimes called mafic) which have little or no silica, but which are made up of considerable lime, magnesium and iron. They are usually dark in color and have a high specific gravity. Certain rocks are between the two and are sometimes classed as intermediate.

The characteristics of the most important igneous rocks are shown in the two following tables.

FELSIC OR ACIDIC

(Mainly light-colored rocks with orthoclase feldspar)

	Contains Quartz	*No Quartz*
COARSE-GRAINED	*GRANITE:* This is a coarse-grained rock, usually white, gray or pink in color. It is made up of a mixture of crystals of quartz and feldspar with minor amounts of other minerals such as hornblende and mica. The proportion of the constituents varies considerably thereby accounting for the differences in color and texture of various granites. One important feature of all granite is that the crystals are large enough to be seen with the naked eye.	
COARSE-GRAINED	*PEGMATITE:* This is a variety of granite with very large crystals up to 20 feet in length. Pegmatites usually occur near the border of granitic intrusions and are thought to have been formed by a fluid magma. Pegmatites are especially common in Maine and the Black Hills of South Dakota.	*SYENITE:* Syenites were formed from magmas that contained less silica than those which formed granite. In other words, there is little or no quartz. Most syenites are composed of orthoclase and hornblende with plagioclase, apatite and magnetite as accessory minerals.
FINE-GRAINED	*RHYOLITE:* This rock is closely related to granite but has much finer crystals which are not visible to the naked eye. The rock is usually somewhat glassy in appearance. It is thought to have cooled more quickly than granite and is usually an extrusive rather than an intrusive rock.	

	Contains Quartz	*No Quartz*
FINE-GRAINED	*OBSIDIAN:* This is sometimes called "volcanic glass." It is an igneous rock that hardened very quickly as it erupted without sufficient time for individual minerals to form. It is harder than glass and breaks with sharp edges. It is usually black but may also be red or gray. It is most common in the southwestern states and Mexico and was formerly used by the Indians for arrowheads, scrapers and other artifacts. It is used today for jewelry and small ornaments.	

BASIC OR MAFIC

(Mostly dark-colored rocks with little or no quartz)

	More plagioclase feldspar	*Less feldspar, more dark minerals*
COARSE-GRAINED	*DIORITE:* This is a coarse-grained rock composed of plagioclase feldspar and some iron-magnesium minerals. It contains little or no quartz and is usually dark in color.	*GABBRO:* This is a coarse-grained rock very similar to diorite but with the darker (ferro-magnesian) minerals predominating over the feldspars. The color varies between bronze and greenish-gray, depending upon the freshness of the ferro-magnesian minerals in the rock. It weathers readily and fresh exposures are rare. *DIABASE:* A diabase has much the same composition of a basalt or a gabbro. However, the feldspar crystals are arranged in a texture of long

	More plagioclase feldspar	*Less feldspar, more dark minerals*
COARSE		interlaced narrow rods. The individual grains can be distinguished with a good hand lens. The texture is intermediate between that of a gabbro and a basalt.
FINE-GRAINED	*ANDESITE:* This is the fine-grained equivalent of a diorite. It is usually dark gray in color and is made up of hornblende, pyroxene, or biotite.	*BASALT:* This is the fine-grained equivalent of a gabbro. It is impossible to distinguish the individual crystals with the naked eye or with a hand lens. Many basalts are of volcanic origin and were formed by the rapid crystallization of basic lava flows; others are of intrusive origin having cooled within the earth.

"TRAP ROCK": This is a general field term used for various dark, basic igneous rocks which cannot readily be distinguished without careful microscopic examination. Thus, gabbro, diorites, diabase and basalt are frequently spoken of as "trap rock." The name comes from the French *treppe* (stairs) because of the stair-like appearance of the eroded edges of a series of flows.

VOLCANIC ROCKS

We have already seen how igneous magmas may intrude sedimentary rocks and not reach the surface of the earth. These are intrusive rocks in contrast to extrusive rocks. Material ejected by volcanoes falls in the latter group. Let us examine a few of these.

BOMBS

The solid fragments ejected by volcanoes vary in size from minute particles (ash) to large blocks of material weighing several tons. These are given various names according to their size and shape, the most usual names being bombs, blocks or the more technical term "pyroclastic debris." Although these large objects are usually not hurled very far, large blocks weighing two or more tons were hurled two miles during a recent eruption of Stromboli in Italy.

CINDERS

This is the term used for smaller particles or debris hurled from the crater of the volcano. While there is no exact distinction between cinders and bombs, it is arbitrarily stated that cinders (or lapilli) are between 32 mm. (about 1¼ inches) and 4 mm. (about ¼ inch) in size. Obviously cinders are transported much farther than blocks or bombs. Many of the cinders ejected from a volcano are in a semiliquid state when they come in contact with the air, and solidify as they cool. The crevices originally filled with steam or other gases remain giving the cinders a very porous character.

ASH

These are the finest particles ejected from a volcano and are generally less than ¼ mm. in diameter. Sometimes the term volcanic dust is used for very fine ash, but generally the two terms are used synonymously. In a sense the word ash does not describe this material. Volcanic ash has not been burned but represents exceedingly fine particles of magma or lava that have been broken into minute pieces by explosive eruptions of the volcano.

The bombs, cinders and ash accumulate near the foot of the volcano and eventually build up a cone-shaped mountain. The

volcano Paricutín which suddenly appeared in a cornfield in Mexico in 1943 built up a cone of this kind 1,200 feet above the surface in less than a year. It continued to build up slowly for another 10 years until it became extinct in 1953. Such a volcano is called a cinder cone. Numerous extinct cones of this kind can be seen in New Mexico, Arizona, Idaho as well as in many parts of Mexico.

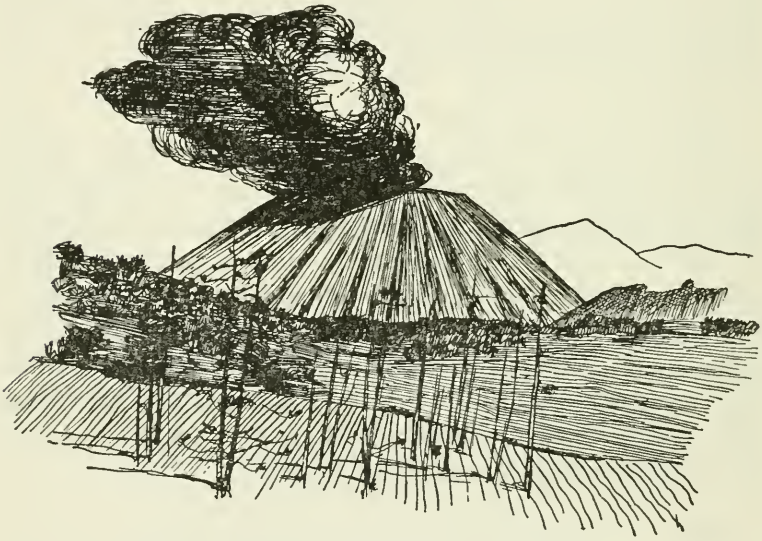


Fig. 69. The volcano Paricutín in Mexico.

Ash can travel great distances. In the case of Paricutín, ash blown from the volcano was so thick in Uruapan 25 miles away that it was necessary to sweep the roofs to prevent them from caving in. Inconspicuous falls of ash were noted in Mexico City some 200 air-miles away.

Ash from other volcanoes has traveled even greater distances. After the tremendous eruption of Krakatao in the East Indies in 1877, ash literally blew around the world. For some months,

after this eruption the small particles of ash in the air created unusually striking sunsets.

While ash will destroy the vegetation on which it falls, it may eventually weather to form a very rich soil. The vineyards at the foot of Vesuvius, for example, have rich volcanic soil of this kind.

All types of pyroclastic debris (bombs, cinders, ash) are relatively loose when they first strike the ground. Eventually they may harden to form a more solid rock. If the resulting rock is composed mainly of fine particles (dust and ash), it is called a tuff; if the resulting rock is made up of larger particles, it is known as a breccia.

LAVA

Lava differs from magma in that the former reaches the surface of the land either through a volcano or by a fissure in the ground (fissure eruption), while the magma is intrusive. In the case of volcanoes the lava can be forced up the crater to the top and then flow down the side of the cone; or, as is frequently the case, the lava may break through a vent in the side of the volcano and flow over the countryside without ever having reached the top. The gases that were in the original magma escape from lava and frequently leave pores similar to those described under cinders and bombs.

Lava can be various material, acidic or basic, and a single volcano can emit different kinds of lava at different times. It may be classified according to its chemical composition, and also on the basis of its consistency or hardness. Lava that is fairly well consolidated and consists of irregular broken pieces of rock as it comes from the volcano is called flow breccia or by the Hawaiian term *aa*. The rate of movement of this type of lava is relatively slow, usually no more than a few hundred yards a day. Other lava is smooth or ropy as it comes from the vent or crater and flows much more rapidly, sometimes

reaching a speed of 15 miles per hour on downhill stretches. The ropy nature of this lava is preserved as it hardens and thus can easily be distinguished from the "chunky" *aa* type. Ropy lava is known by the Hawaiian name *pahoehoe*.

10

Metamorphic Rocks

THE WORD *metamorphic* comes from the Greek and means "changed form." Metamorphic rock can be formed from sedimentary, igneous or from other metamorphic rocks. Metamorphism usually involves heat and pressure. The original rocks are frequently buried under tremendous thicknesses of younger rocks, and it is the weight of this covering that is partly responsible for the pressure. The heat may come from igneous activity or from exceedingly hot waters from deep within the earth. The lapse of a considerable interval of time is usually involved in the process.

The metamorphism of a rock usually involves melting and complete recrystallization. In most cases it is possible to determine what the original rock was, but in cases when the metamorphism has been very intense, this is impossible, and it is sometimes even impossible to say whether the original rock was igneous or sedimentary.

Metamorphic rocks are usually harder than the sedimentaries and as hard or harder than igneous rocks. Because of their hard crystalline nature, metamorphic rocks are frequently called crystallines.

Metamorphism is frequently associated with mountain building; consequently many metamorphic rocks are found in mountainous country, for example, the Appalachians, the Rockies, the Alps, etc. Even in the case of those metamorphic rocks that are not near present-day mountains, it can often be shown

that mountains did exist in that region at the time when the metamorphic rocks were formed and that later erosion has leveled them to low hills or a level plane.

In examining some common metamorphic rocks, we find, as in the case of the igneous rocks, accurate recognition usually requires a microscopic examination; nevertheless, a few of their characteristics can be mentioned here.

It is convenient to divide the metamorphic rocks into two classes, the foliates and the non-foliates.

FOLIATES

These rocks are composed of considerable amounts of the minerals mica and chlorite. Since these minerals show good cleavage, it generally follows that foliated metamorphic rocks will easily split in a plane parallel to the cleavage of these mineral constituents. The word foliate comes from the Latin *folia* meaning sheets, as in the pages of a book.

SLATE

We have seen earlier in this chapter that silt or clay becomes consolidated to shale. The resulting rock is reasonably soft and the original stratification or bedding is retained. If a shale is subjected to metamorphism, an entirely new fine-grained rock is formed. This is a slate. A new cleavage plane appears which may be parallel to the original bedding, but in most cases is at a pronounced angle to it. The original bedding can frequently be seen as faint streaks, sometimes highly folded during the process of metamorphism.

PHYLLITE

This is a finely micaceous rock exhibiting the characters of foliation. It is slightly coarser than a slate and is usually rather greasy to the touch. The mica flakes are frequently large enough to be seen with the naked eye, but most of the other

minerals are microscopic. Phyllites represent a degree of metamorphism intermediate between a slate and a schist.

SCHIST

This rock is coarse enough so that the individual grains can be distinguished with the naked eye. It has been squeezed harder than slate and is often greatly folded and crumpled. The individual "leaves" are usually of variable thickness. Many of the original minerals have been altered to flakes thereby accounting for "schistose cleavage." Schists are usually classified by their principal mineral constituents such as mica schist, hornblende schist and talc schist.

GNEISS

A gneiss is coarser than a schist and lacks the characteristic schistose cleavage. A gneiss is banded with the alternating layers generally being composed of different mineral assemblages. Feldspar is an important constituent of gneiss while other minerals include mica and quartz.

A gneiss indicates an extreme degree of metamorphism of either a sedimentary rock such as sandstone or shale, or of an igneous rock such as granite. Or, it may indicate a second stage of metamorphism (hypermetamorphism) of an already metamorphosed rock such as a slate or schist. One of the most common types of gneiss is a granite gneiss which sometimes can be differentiated from its original granite only by microscopic examination.

NON-FOLIATES

These are metamorphic rocks that do not show any cleavage of foliation.

QUARTZITE

This is a metamorphosed sandstone. The individual grains

have been firmly cemented together, usually by silica carried in solution in hot waters intruded into the rock from deeply buried magmas. The resulting quartzite is consequently much harder than the original sandstone. An easy method of differentiating sandstone from quartzite is to break the rock. When a sandstone is broken, it breaks around the grains, while quartzite when broken, breaks across the grains.

MARBLE

When limestone or dolomite becomes metamorphosed, it is called marble. This is a hard crystalline calcareous rock of which the principal minerals are calcite or dolomite. Marble is very variable in grain size and color, the differences in color generally being caused by impurities such as iron or other minerals. Unlike limestone, marble does not fizz with dilute acid.

SOAPSTONE OR STEATITE

This is a very soft rock composed mainly of the mineral, talc. It is usually very greasy to the touch—hence its common name soapstone. Pieces of steatite are occasionally used for ornaments, while the main constituent, talc, is the chief source of talcum powder.

SERPENTINE

Serpentine is usually dark green in color with streaks of whitish calcite. It was formerly extensively used as a building stone, but it has been found that it tends to decompose when attacked by impurities in the air.

COAL

We have already discussed the formation of coal as a sedimentary rock (p. 104). When soft (bituminous) coal is metamorphosed by heat or pressure it becomes hard (anthracite)

coal. It does not necessarily follow that hard coal is any older than soft. It is merely a matter of whether metamorphism has taken place. Eastern Pennsylvania is famous for its hard coal, while the western part of the state has its soft coal deposits. Actually, these are of exactly the same age and certain specific layers or seams can be correlated from Scranton to Pittsburgh. However, eastern Pennsylvania was subjected to intense metamorphism in connection with the rise of the Appalachian Mountains during Permian time, while this activity did not extend to the western part of the state.

11

Minerals

As WE HAVE SEEN in the previous chapter, the terms rock and mineral are sometimes used interchangeably, although they are actually entirely distinct. Minerals are the fundamental units, which in turn make up rocks. We have chosen to describe rocks first and now to turn to the minerals which make up the rocks. Some might have preferred the reverse — that is discussing the minerals before describing the rocks in which they occur. It actually makes very little difference which is discussed first because the two are so closely interrelated that it is impossible to understand one without the other. It will consequently be necessary for the reader to refer occasionally from one chapter to the other to obtain the proper understanding of the relationship of rocks and minerals.

We have seen in the previous section that each mineral has a definite chemical formula (within limits). In addition they also have certain other properties which are relatively constant. These include crystal form, hardness, luster, streak, and to a lesser extent color, all of which are made use of in the identification of minerals.

PROPERTIES OF MINERALS

When one attempts to identify an unknown mineral, it is desirable to consider as many properties as practicable. In the case of the more common, and some of the rarer, minerals, it is possible to reach an identification by a study of their various

physical properties without recourse to chemical or optical analysis. In other cases, chemical analysis (blowpipe) or optical studies of crystal form will be necessary. Let us first examine the physical properties.

COLOR

This is, of course, the most obvious property, but one which unfortunately cannot always be used alone to determine a mineral. It is true that azurite is always blue and carnotite yellow, but such common minerals as quartz, calcite and mica can be almost any color because of impurities. On the other hand, color can be used as one of the various criteria for identification of minerals. A trained mineralogist knows the usual color variations of a given mineral, as well as the particular minerals which show little or no variation in color. Color may also be used by the process of elimination, for many individual minerals never occur in certain colors, and thus the field may be narrowed.

STREAK

This property is frequently more useful than color. It is the color of the powder of the mineral and can be seen by scratching the mineral on something harder than itself. For minerals of not too great hardness the streak may be obtained by scratching it on a "streak plate" of unglazed porcelain which can be purchased from mineral dealers. The streak test will often give a truer indication of the color of the mineral because surface impurities are eliminated.

LUSTER

This term indicates the "shinyness" of a mineral. In a sense it is an arbitrary property, but one which when taken with various other properties will often help in the identification of an unknown specimen. The terminology of luster is not stand-

ardized, but the following table covers the main terms used in this connection.

Metallic: Looks like metals; color range not great; usually metals or metal sulfides, e.g. pyrite and galena.
Non-metallic:
Vitreous: glass-like, e.g. quartz
Resinous: less brilliant, resembling rosin, e.g. sphalerite.
Greasy: still less brilliant; appearing as though grease-covered.
Silky: with a sheen connected with fibers, e.g. asbestos.
Pearly: iridescent, e.g. talc.

HARDNESS

This also is an arbitrary property, but one that has proved to be exceedingly useful in mineral recognition. The scale now in use was invented by the German mineralogist Frederick Mohs in 1822 and consists of a series of ten minerals arranged in an order of increasing hardness:

1. Talc
2. Gypsum
3. Calcite
4. Fluorite
5. Apatite
6. Feldspar
7. Quartz
8. Topaz
9. Corundum
10. Diamond

All minerals are referred to one of the above in respect to hardness. Thus pyrite is said to have a hardness of between 6 and 6.5 because it is slightly harder than feldspar. It can be scratched with anything with a greater hardness number and in turn can scratch any mineral with a lesser number.

The minerals were chosen because they are common ones, not because they are of a particular hardness. The minerals do not get harder to the same degree from one number to the next; therefore it cannot be said that gypsum is twice as hard as talc, or that it is exactly halfway between calcite and talc in hardness. Diamond is probably about 1,000 times as hard as talc compared to the other minerals.

The following table shows the approximate hardness of certain common objects, and may be useful in determining the hardness of unknown minerals.

1	
Soapy feel	
2	
Fingernail	
3	
Penny	
4	
Easy to scratch with a knife	
5	
Hard to scratch with a knife	
5½	
Will scratch plate glass	
6	
Scratched with steel file	
7	
Scratched by piece of quartz crystal	

CLEAVAGE

A mineral may have a tendency to break along definite parallel planes depending upon its crystal structure. This property is frequently very characteristic and can easily be determined by striking a piece with a hammer or by attempting to split it with a chisel or knife blade. The planes along which the mineral breaks are called the *cleavage planes*. Minerals are said to have perfect cleavage when they split easily along a definite plane, as in the case of mica. Many minerals have two or more cleavages and their cleavage fragments may be cubic, prismatic, octohedral, etc. On the other hand, certain minerals such as quartz have no cleavage.

FRACTURE

Somewhat related to the property of cleavage is that of

fracture. This refers to the character of the surface when the mineral is broken at random along lines other than the cleavage planes. Minerals with poor or no cleavage generally fracture relatively easily. The following are some of the general terms used in describing fracture:

Conchoidal	surfaces curved	e.g. quartz
Even	flat; on even planes	e.g. lithographic limestone
Uneven	wavy	e.g. rhodinite, bauxite, kaolin
Hackly	rough with sharp points	e.g. copper
Splintery	in splintery fibers	e.g. asbestos

SPECIFIC GRAVITY

This is the weight of the mineral in relation to the weight of the same volume of water. Water is taken to have a specific gravity of 1.0 and accordingly substances twice as heavy as the same volume of water would have a specific gravity of 2.0. Each mineral has a definite specific gravity which is recorded in all textbooks and manuals of mineralogy. Certain especially heavy ones such as barite can often be approximately identified by tossing a piece up and down in one's hand.

FLUORESCENCE

Certain minerals have the property of changing ultraviolet rays, normally invisible, to ordinary visible light rays. These minerals appear to glow when they are subjected to ultraviolet rays in total darkness. A simple exhibit can be prepared by mounting certain minerals in a case and placing the case in a completely dark room and then flooding the assemblage with ultraviolet light.

Some fluorescent minerals continue to glow after the ultraviolet light has been turned off. This property is known as phosphorescence and is possessed by relatively few minerals.

The famous zinc mines at Franklin, New Jersey, are noted for fluorescent minerals, especially willemite.

CLASSIFICATION OF CRYSTALS

Most common minerals are crystalline, in other words they grow in regular geometrical forms with definite plane surfaces. In many cases the crystalline nature of the substance is not apparent on surface examination alone, but is brought out by study with the petrographic microscope or the X-ray camera.

Not all substances are crystalline; some are made up of particles or atoms that are not arranged in an orderly fashion, and are spoken of as *amorphous solids;* common examples are glass, rubber, opal and glue.

The science that concerns the structure and classification of crystals is known as crystallography. This is rather complicated and requires some knowledge of Chemistry and Physics as well as Mineralogy, in view of the necessity of measuring angles between surfaces, and of studying the inner structure of crystals by X ray and other complicated equipment. All this is of great importance to the advanced student of minerals, but will not concern the new earth scientist. Suffice it to say that crystals are divided into six systems which in turn are divided into 32 classes.

CHEMICAL CLASSIFICATION OF MINERALS

About 1,500 minerals are known, although many of these are very rare and are of interest mainly to the specialist. Obviously some sort of system is necessary to enable the mineralogist to classify his specimens. We have already mentioned the classification based upon the formation of the crystals, and it would be possible to devise a system of classification of all minerals based upon crystallography without regard to composition. While this may be satisfactory for some workers, the more usual approach to classification is on the basis of chemical composition.

The standard work on the classification of minerals is *Sys-*

tem of Mineralogy by J. D., and later his son, E. S. Dana, a book which originally appeared in 1837, and which has been revised numerous times, the most recent issue being the seventh edition revised and rewritten by Charles Palache, Harry Berman and Clifford Frondel and planned to be in three volumes of which two have now appeared.

Although the ten-part classification of Dana is the most scientific and most generally accepted, it will not be discussed any further here. To begin with, a full understanding of it requires some knowledge of chemistry, not only the names of the elements, but, for example, the differences between sulfates and sulfides, etc. Furthermore, it is not the intention of this book to discuss any large number of minerals. Rather, it is our purpose to introduce the beginner to the study of minerals, to tell something of their significance and to give a few examples of different kinds of common ones. Therefore, it seems simpler to group the minerals described later in this chapter under the iron minerals, copper minerals, etc. If the reader desires more information on the standard classification — and we hope he will — he can refer to some of the books cited in the bibliography.

12

A Mineral Collection

In a previous section we have attempted to tell the beginner where to look for fossils. Since the amateur earth scientist will want to know something about both minerals and fossils and to have representatives of both groups in his collection, he will naturally ask the question "Where shall I look for minerals?"

He will have found out how certain minerals are characteristic of sedimentary, igneous and metamorphic rocks. This will be the start. By actual observation, or by consulting geological maps he will find out what kind of rocks occur in the vicinity of his home, and consequently he may know what kind of minerals to look for.

In this case it is not absolutely necessary to know the geological age of the different formations, inasmuch as similar suites of minerals can be found in diabase whether it be of pre-Cambrian, Devonian or Triassic age. It is, however, helpful to learn the age of the rock, especially if one wants to understand the geological history, and in some cases the association between the minerals and the fossils.

Again, as in the case of the fossil hunter, the mineralogist would do well to consult the publications of his State Geological Survey, or the surveys of other states in which he is interested. Not only can he purchase useful geological maps, but frequently he can find actual lists of minerals known from

the state as well as lists of quarries or mineral localities.

Since there are more amateur mineral hunters ("rock hounds") than fossil hunters, it will be relatively easy for the mineralogist to find a group of people with similar interests. There are a great many societies or clubs made up of amateur (and a few professional) mineralogists who always welcome enthusiastic beginners, and will encourage them to come to their meetings and field trips. These organized field trips should be most helpful to the beginner, not only because of the minerals that he may collect, but because of the information that he will glean from the leaders and fellow members. Field trips of this kind often lead to valuable friendships and important exchanges of specimens.

Speaking of exchanges, these should not be limited to fellow members of your local society, but should be extended to points far afield. From his own local club the young earth scientist may be able to learn the names of members of similar groups in other sections of the country, and thus to start correspondence and exchanges.

It should be easy to locate a suitable mineralogical society. If there is any difficulty, one should inquire from his State Geological Survey, or from the Department of Geology at the nearest university or college. Certain magazines such as *Rocks and Minerals, Gems and Minerals, Earth Science Digest,* and *The Lapidary Journal* are published primarily for the amateur, and one can often learn of the activity of clubs or of the possibility of buying or exchanging specimens.

It may be well to repeat one word of caution that we gave in connection with instructions to the fossil hunter. Remember that quarries are private property, and also many of them are very dangerous. Therefore, the collector should be very careful to obtain permission before investigating any property whether it be a quarry, active or abandoned, or merely an excavation in somebody's back yard.

HOW TO COLLECT MINERALS

As in the case of fossils, this will vary with the location and the desires of the collector. Most minerals occur in hard rock making it necessary to extract the specimen from the surrounding matrix. A good prospector's pick or hammer is a must. The best kind has one blunt end and one pointed end. This will be useful for general purposes including both mineral and fossil hunting. A chisel is often helpful in extracting difficult specimens.

It is generally good policy not to attempt to extract the specimen in the field, but rather to take it back in a moderate-sized piece of rock, and then do the careful extracting at home or in the laboratory. Collecting bags, wrapping paper, labels, a note book, and a good magnifying glass are also necessary tools for the mineral collector. Again, as in the case of the fossil collector, it is essential that the minerals be labeled as to locality. One may think that he will remember the locality for each specimen, but it is wiser to play safe and label each specimen as it is collected. Some "rock hounds" carry a bottle of weak hydrochloric acid with them in the field in order to test for limestone and other carbonates that will fizz in contact with this acid. Others prefer to make these tests, along with those of hardness, back in the laboratory. And speaking of hardness, a "hardness set" with examples of the first nine degrees of hardness is an extremely helpful item to have in the laboratory.

HOW TO KEEP MINERALS

The size of your collection will be limited mainly by your own enthusiasm and space considerations. Obviously, people living in a small apartment should not attempt to build up as large collections as those with more space available, and one

must avoid inflicting a hobby on less interested members of the family.

The specimens should be cleaned and cut to a reasonable size and then placed in small trays or in cabinets. It is unlikely that examples of all 1,500 minerals, or even a large percentage of them, will be obtained. On the other hand, it is desirable not to have too many examples of any one kind of mineral. It is well to discard poor specimens as better examples come your way. Of course, it is nice to have examples that show the variation of a given mineral or to have specimens from a number of different places, but too much duplication detracts from the appearance of a collection.

Suggestions were given to the fossil collector about cataloguing his specimens. These same remarks will apply to the mineral collector, except that in this case there is one short cut used by many professionals. We have seen that Dana's *System of Mineralogy* (7th edition) has classified the minerals according to a definite plan—that is in various major classes. Each mineral has been given a number which can always be found by referring to this book. A loose-leaf notebook might be devised with a page, or part of a page for each mineral with its appropriate number. Thus 17 would be pyrite. On the page 17-1 would indicate the first specimen of pyrite obtained with the locality recorded. 17-2 would be another piece of pyrite with a different locality recorded. A small dab of white paint could be applied to the mineral so that the catalogue number could be written in India ink. This is safer than merely labeling the box in which the minerals are kept since the specimens might accidentally be put back in the wrong box.

HOW TO IDENTIFY MINERALS

We have already discussed the various physical properties of minerals that can be more or less readily determined without

recourse to complicated equipment. These include cleavage, color, streak, and hardness. One property alone will not determine the minerals, but usually knowledge of several of these factors will narrow the field so much that the specimen can be identified.

However, especially in the case of the rarer minerals, these factors alone may not be sufficient and one must resort to more scientific tests. We have already discussed the importance of crystallography. The use of a goniometer for measuring angles, an X-ray camera for determining atomic structure, and a polarizing microscope to determine optical properties will reveal features not recognized by simpler methods. Furthermore, chemical tests with the use of a blowpipe and numerous reagents such as acids, borax, charcoal, sodium carbonate, and a platinum wire will be very helpful in determining the chemical composition of unknown minerals. However, these optical and chemical tests, especially the former, are generally beyond the scope of the beginner, and are merely mentioned here for the sake of completeness. In general, the properties discussed in this book and recorded under the characteristic minerals will be sufficient for the recognition of a large number. When the collector has learned to recognize the common forms, it will be time enough to look into the more elaborate tests and then he should consult one of the more advanced references cited in the bibliography. However, much pleasure and knowledge can be obtained by attempting to identify minerals by the less complicated methods described on previous pages.

MINERALS

Iron Minerals
- Magnetite
- Siderite
- Hematite
- Limonite

Copper Minerals
- Native Copper
- Malachite
- Azurite
- Bornite
- Chalcopyrite
- Cuprite
- Chalcocite

Aluminum Minerals
- Kaolin
- Bauxite
- Cryolite

Chromium Minerals
- Chromite

Lead Minerals
- Galena

Zinc Minerals
- Sphalerite
- Smithsonite

Manganese Minerals
- Rhodochrosite

Titanium Minerals
- Rutile
- Ilmenite

Gold Minerals
- Gold

Uranium Minerals
- Uraninite
- Carnotite

Sulfur Minerals
- Sulfur
- Pyrite

Phosphorus Minerals
- Apatite

Calcium Minerals
- Calcite
- Dolomite
- Gypsum

Miscellaneous Non-Metallic Minerals
- Mica
- Feldspar
- Quartz
- Halite
- Graphite

Serpentine Minerals
- Serpentine
- Talc

Gem Minerals
- Diamond
- Beryl
- Garnet
- Tourmaline
- Zircon

13

Some Typical Minerals

AS WE HAVE STATED several times, it is not the purpose of this book to serve as a guide for even the most common of minerals. Various books such as those cited in the bibliography do just that. In the following section we have selected some forty-one minerals, most of which will be familiar, at least by name, to the majority of readers. While we have not attempted to describe them fully, we have given a few of their properties which will help in their recognition and have included a brief discussion of their economic importance and distribution. For convenience, these minerals have been grouped according to their most important constituent from an economic point of view, that is the iron minerals, the copper minerals, etc. The metallic minerals will be discussed first, followed by the non-metallic examples.

IRON MINERALS

Iron is the most important of the metallic elements and one that is found in practically all parts of the world. Although iron has been used by man for more than 2,500 years—ever since the Iron Age—it was not until 1857 with the development of the Bessemer process for making steel cheaply that iron assumed the vital role in our economy that it does today.

During recent years about 80 per cent of the ore used in the United States has come from the Lake Superior region of

Minnesota, Michigan, Wisconsin, and adjacent parts of Canada, especially from the Mesabi range of Minnesota. This ore is chiefly hematite and is of pre-Cambrian age. A few years ago it was realized that the rich iron deposits of the Lake Superior region were becoming depleted and consequently many of the major iron and steel companies began to search for reserves that could be used to fill the country's future needs. Among the important recent discoveries are those of the Quebec-Labrador border in Canada and those of Cerro Bolívar in eastern Venezuela.

Second in importance to the Lake Superior deposits are the Clinton iron ores that have been mined in various states from New York to Alabama, especially in the latter state between Birmingham and Bessemer. These ores are largely hematite with some limonite and are sedimentary in origin, of Silurian age.

The magnetite deposits of the Adirondacks in New York State as well as in northern New Jersey and Pennsylvania are also important sources of iron. The hematite ores of the Straits of Belle Isle in Newfoundland, although unusually high in phosphorus content, are important for the steel industry of Canada. Smaller iron deposits occur in the great majority of the forty-nine states.

HEMATITE

This ferric oxide is the most important ore of iron; it may be red or black although the streak is always red; it has a metallic or earthy luster and a hardness around 5.0. Hematite may occur as crystals, or more frequently in compact, granular or earthy masses; it has no cleavage, but breaks with a conchoidal or uneven fracture. Hematite frequently forms from the weathering of other iron-bearing minerals and accounts for the reddish color of many sedimentary rocks and soils.

LIMONITE

Limonite or ferric hydroxide is frequently formed by the weathering (oxidation and hydration) of other iron minerals and thus may be regarded as a form of "iron rust." It is dark yellow, brown, or black in color with a yellow-brown streak. Its hardness is usually between 5 and 5.5, although some varieties may be much softer. Although usually amorphous, it may be minutely crystalline.

MAGNETITE

Magnetite, another iron oxide, has a black color and streak, a metallic luster and a hardness of about 6. It can be distinguished from similar minerals by its magnetic properties. Magnetite is an important iron ore and may occur in igneous rocks such as gabbro, diabase and basalt (see p. 110), in metamorphic rocks, or in sands. The black sand of many sea beaches are made up largely of this mineral, although some may be ilmenite instead. (page 144.) Magnetite occurs in most parts of the United States. Good crystals have been found at French Creek, Pennsylvania, Cornwall, Pennsylvania, and Brewster, New York. Exceptionally magnetic material comes from Magnet Cove, Arkansas, and is known as *loadstone*.

SIDERITE

Siderite is an iron carbonate and a minor source of iron. It is brown, gray, or black in color with a white or yellow streak. It has perfect cleavage, a conchoidal fracture and a hardness of between 3.5 and 4.5. Siderite frequently occurs in sulfide ore deposits as well as in sedimentary limestones and shales as concretions. Although it occurs with other commercial iron minerals in New York, Connecticut, Vermont, and Colorado, it is of greater economic importance in the mines of

England and elsewhere in Europe. Noncommercial deposits are widespread in the United States.

Massive limonite, called ironstone, is occasionally used for building. A soft, earthy variety of limonite, intimately mixed with clay and sand, is termed yellow ochre and is used for certain paints. Bog iron ore, now being formed in marshy and swampy places by the action of certain bacteria, is also to be regarded as a variety of limonite. This was a very important source of iron during the Revolutionary War, but the industry died out early in the eighteenth century after the discovery of rich iron deposits in Pennsylvania and farther west. Ruins of many deserted iron furnaces and forges can be seen today hidden in the pine forests of central and southern New Jersey. Today about 4 per cent of the iron mined in the United States comes from limonite.

COPPER MINERALS

Copper ranks next to iron in importance as a metal. Bronze, an alloy of copper, was used by Early Man and has given the name Bronze Age to a cultural stage in Europe approximately 5,000 to 3,500 years ago. The greatest increase in the use of copper during recent years has been connected with the electrical industry, especially for wires, about half of the copper in the United States being utilized for this purpose. Fortunately, much of the copper so used, when no longer needed, can be salvaged and reused repeatedly. At the present time the United States is the main producer and user of copper.

The copper minerals of greatest economic importance are native copper, chalcopyrite, bornite, cuprite, azurite, malachite, and chalcocite.

There are two main ways in which the copper ores occur. They may be disseminated or mixed throughout the rock, or

they may be concentrated in veins or lodes. Both are of considerable economic importance.

The most important copper-producing state is Utah, the principal mines being those of the Kennicott Company near Bingham. In this region Carboniferous limestones and quartzites were intruded by igneous rocks causing the dissemination of various copper minerals throughout the mass. The chief ore mineral is chalcopyrite, which occurs both in the sedimentary and the igneous rock.

Montana ranks second in the mining of copper, mainly because of the important mine at Butte and Anaconda. Here the copper minerals are chiefly chalcocite and bornite along with various other minerals such as sphalerite, galena, gold and silver. The minerals occur in fissures or veins in a great intrusion of granite (the Boulder batholith) which rose in the region about the time of the uplift of the Rocky Mountains at the end of the Cretaceous period.

Arizona is third in the mining of copper with important mines near Bisbee, Globe, Jerome and Ajo.

Michigan is important because of the mines in the Keweenaw Peninsula which yield an abundance of native copper and other copper minerals associated with basic lava flows of pre-Cambrian age. Native copper was mined by the early Indians of this region and traded widely for ornaments. Mining there is on the decline because of the great depth to which the deposits have been mined away.

Other notable copper deposits occur near Robinson, Nevada, Ducktown, Tennessee, Sudbury, Ontario, and elsewhere in Canada. Copper minerals are frequently associated with those of lead and nickel.

NATIVE COPPER

This is one of the relatively few elements which occurs pure in nature as a mineral. It is generally in scales, stringy

masses and lumps, sometimes many tons in weight. Crystals are fairly common, although they are usually highly distorted. Native copper has no cleavage and breaks with a hackly fracture. The hardness is between 2.5 and 3. The color is red on fresh exposure, but the mineral quickly tarnishes to black, green or blue.

Although native copper is best known from the Keweenaw Peninsula of Michigan, it also occurs along with other copper minerals in Arizona and New Mexico.

MALACHITE

Malachite, or copper carbonate is an important copper ore especially in Arizona. It is bright emerald green to nearly black in color and has a light green streak. It has a conchoidal or splintery fracture and a hardness of 3.5 to 4. It is used for jewelry and/or ornamental purposes. It is frequently associated with azurite.

AZURITE

This mineral, also a copper carbonate, frequently occurs with malachite. Both color and streak are blue and the hardness is about 3.5. Azurite crystals are fairly common in copper mines in Arizona as well as locally in Utah and California.

BORNITE

Bornite, a copper iron sulfide, usually occurs in compact and granular masses and is very rare in the crystalline form. It has poor cleavage, uneven fracture, a metallic luster and a hardness of 3. The color of fresh exposures is bronze, but tarnishes to blue, purple, and black and is often iridescent, giving rise to the term "peacock ore." The streak is gray.

Bornite frequently occurs with other copper minerals especially chalcopyrite and is common in Montana, although specimens are also known from Virginia, North Carolina, Connecticut and elsewhere.

CHALCOPYRITE

This is the most common copper mineral and occurs in practically all copper ores. Like Bornite, it is a copper iron sulfide. It is yellow in color with a greenish-black streak. Crystals are common and are often large. The cleavage is poor and the fracture uneven; hardness is 3.5 to 4.

Chalcopyrite is frequently associated with gold or silver as well as sulfides of other metals.

CUPRITE

This is another important copper mineral which occurs widely in Arizona and the Lake Superior region. It is a cuprous oxide, red to black in color with a brownish red to brown streak. Crystals are common, although it also occurs in a massive earthy form. The hardness is 3.5 to 4. Cuprite is a secondary mineral resulting from the oxidation of various copper minerals. It alters readily to malachite, azurite and native copper.

CHALCOCITE

This is a gray mineral which tarnishes to blue or green; the streak is lead-gray. It is frequently in veins along with bornite, chalcopyrite, galena and other minerals. It is especially abundant in the copper mines in Arizona, Montana, Utah and northern Mexico. Chalcocite is a cuprous sulfide.

ALUMINUM MINERALS

Aluminum is, next to oxygen and silicon, the most abundant element present in the rocks making up the surface of the earth. It is represented by a great many minerals of which only a few can be discussed here. The feldspars are important constituents of many igneous and sedimentary rocks. These readily weather to form kaolin, the main constituent of common clay.

The chief ore of aluminum is bauxite which is abundant in the Guianas and Brazil as well as in parts of southeastern United States. Cryolite is important in the extraction of aluminum from bauxite. Feldspar, muscovite and biotite are other aluminum minerals which will be briefly discussed in succeeding paragraphs.

Fig. 70. Bauxite.

KAOLIN

This is one of many clay minerals which is formed by the weathering of feldspar or other aluminum-bearing minerals. It is, accordingly, one of the most abundant of all minerals and occurs in all parts of the United States. Because of the minute size of the particles it is impossible to determine the characteristics of the clay minerals by ordinary means.

The main use of kaolin is in the ceramic industry. Recently various other uses of pure kaolin have been developed, for example, for the manufacture of coated paper, rubber and other products.

Kaolin is a potential source of metallic aluminum, but at present the methods of extraction are too costly to compete with the use of bauxite.

BAUXITE

This is the chief ore of aluminum and occurs abundantly in the Guianas and Brazil, and less so in Arkansas with smaller deposits in Georgia, Alabama, Tennessee and elsewhere. The town of Bauxite, Arkansas, is the center of the industry in the United States.

Bauxite varies in color and streak between white, brown and yellow. It has a dull to earthy luster with a hardness of between 1 and 3. Bauxite is formed by the decomposition or weathering of various kinds of rocks such as granite and gneiss and thus may be regarded as a secondary mineral. It is believed that bauxite generally forms under humid semitropical conditions and that most of the bauxite of the United States formed during the Eocene. Chemically, bauxite may be defined as a "hydrated aluminum oxide."

CRYOLITE

Cryolite, a fluoride of sodium and aluminum is used primarily as a bath in the manufacture of aluminum and is obtained mainly from pegmatite dikes at Ivigtut, Greenland. Small deposits of the same mineral are known from Creede, Colorado.

The crystals are block-like, usually snow white in color with a pearly luster, prismatic cleavage and a hardness of 2.5 to 3.

CHROMIUM MINERALS

Chromium is important as an alloy constituent of armor plate and stainless steel. It is also used for the plating of automobile trimmings. The most important producers of chromium are the Soviet Union, Southern Rhodesia, Turkey, South Africa, Cuba and the Philippines, with the United States producing only 2.5 per cent and Canada 0.5 per cent of the world total. The main American production comes from California.

CHROMITE

Chromite, an oxide of iron and chromium, usually occurs in fine granular masses in veins or as disseminated grains. It is generally associated with serpentine, talc, corundum, etc. It has indistinct octahedral cleavage, a hardness of about 5.5 and is black to brown in color with a gray-brown streak.

Chromite is the only ore of chromium and while the American commercial deposits are largely restricted to California, occurrences have been reported from Maryland, North Carolina, New York and New Jersey, mostly in association with serpentine rocks.

LEAD MINERALS

Lead has been used by man for countless generations. It is mentioned in the Old Testament and lead coins have been found in archeological excavations in Egypt, Babylonia (Iraq) and China.

At present the United States leads the world in producing lead with important mines in southwestern Missouri, northern Idaho, as well as in Utah, Oklahoma and Colorado. Canada (British Columbia) and Mexico are also important lead producers.

The lead ores of Missouri contain little or no silver, while those from the West often contain considerable silver and antimony.

GALENA

This is an iron sulfide and the chief source of metallic lead. It frequently occurs in cubic crystals, has perfect cubic cleavage, a hardness of 2.5 and a metallic luster especially on the cleavage surfaces. It is gray in color with a gray-black streak.

It occurs in veins in igneous and sedimentary rocks and is often associated with silver minerals.

Crystals of galena are used as detectors in radio equipment.

ZINC MINERALS

Zinc, like copper and lead, has been used for many hundreds of years. A bracelet, largely of zinc, was found on the island of Rhodes and coins containing considerable zinc have been found in various Roman excavations.

The United States is the main zinc producer of the world. The most important zinc mines occur in a "Tri-State area" in southwestern Missouri, northeastern Oklahoma and southeastern Kansas.

Another important zinc mine is that of the New Jersey Zinc Company, at Franklin, New Jersey, where pre-Cambrian gneiss and marble have been cut by dikes of pegmatite (see p. 108). The most important zinc minerals at Franklin are zincite, willemite and franklinite. The same company has recently opened the old mines at Friedensville, Pennsylvania, where sphalerite and other zinc minerals are known to occur.

SPHALERITE

Crystals are common, but often distorted. Cleavage is perfect; the hardness is 3.5 to 4. Color is usually yellow or brown, with a white streak.

Sphalerite is a zinc sulfide and the chief source of zinc. It may be looked for in dolomitic limestones and other sedimentary rocks as well as in crystalline metamorphic rocks.

SMITHSONITE

This mineral is zinc carbonate and occurs in limestones and dolomites where it is formed by the action of carbonated waters on other zinc minerals. When pure it is white or yellow, but the color may vary considerably when some of the zinc is replaced by copper (green or blue), or cobalt (pink). It may occur in small crystals or in a porous, earthy variety, the latter known as "dry-bone ore."

Smithsonite is mined commercially at Leadville, Colorado, while the best crystals have come from the Kelly Mine at Magdalena, New Mexico. Other specimens have been collected in Missouri, Arkansas, Iowa, Wisconsin and Virginia.

MANGANESE MINERALS

Manganese, an important metal for the steel industry, is very poorly represented in North America. The United States produces only 2 per cent and Cuba 4 per cent of the world's supply. The most important sources are the Soviet Union with 44 per cent, Ghana with 10 per cent as well as South Africa, Brazil and a few other countries.

In the United States, Montana is the most important producer.

RHODOCHROSITE

This mineral is usually rose-red in color with a vitreous or pearly luster and hardness of 3.5 to 4.5. It may occur in small crystals or in granular masses or crusts on other minerals.

Rhodochrosite is not a common mineral. While the best American specimens have come from mines in the western part of the United States, the mineral is also known from New Jersey (Franklin), Virginia, Tennessee and elsewhere.

TITANIUM MINERALS

Titanium minerals are used to a small extent in the steel industry and in the manufacture of certain paints and pigments. The domestic supply is largely limited to Florida, Virginia, and New Jersey, while imports come from Brazil, India and Norway. The three most important titanium minerals are rutile, ilmenite and titanite.

RUTILE

Rutile, or titanium oxide, frequently occurs as striated prisms

in veins in igneous and metamorphic rocks. It is red, brown or black in color with a yellow or pale brown streak. It has prismatic cleavage, a metallic adamantine luster and a hardness of about 6.5.

In addition to primary deposits in the crystalline rocks, rutile along with ilmenite (iron titanium oxide) forms an important constituent of the "black sands" that occur at many places along the Atlantic Coast where it has been concentrated by streams flowing seaward from the high lands.

GOLD MINERALS

GOLD

Most of the gold mined in the United States comes from placers or is disseminated in quartz veins associated with various sulfide minerals, especially pyrite. Gold is mined extensively in California, South Dakota, Alaska, Colorado, Utah and Nevada. Canada is also an important producer with mines in Ontario, Quebec and Manitoba.

Crystals of gold are rare, the mineral usually occurring as scales or grains or in large lumps known as nuggets. It has no cleavage, a hackly fracture and a hardness of between 2.5 and 3.

Although commercial gold is generally limited to the above-mentioned areas, small pieces of gold may be looked for in a wide variety of localities.

URANIUM MINERALS

The uranium minerals are probably the most sought-after minerals in the world today because of their use for the creation of atomic energy. One of the uranium minerals, pitchblende, is also very important historically because it was the original source of radium discovered by the Curies in 1898.

As is well known today, uranium minerals are radioactive, in

other words they break down spontaneously and at a uniform rate. We have already seen how this uniform rate of decay is used to determine the age of certain rocks and from that the age of the earth (p. 30). As these radioactive minerals disintegrate, they change to other elements and in the process give off energy. This energy is the source of atomic power. The instrument most useful for the determination of radioactivity is the Geiger counter. This records the radioactivity by means of flashes, "clicking" sounds, or by movement of a dial. Portable Geiger counters are standard equipment for many geologists, both amateur and professional.

URANINITE

This is an oxide of uranium and one of the important sources of that element. It occurs in both a crystalline form and as a massive variety, the latter known as pitchblende.

Uraninite occurs in pegmatites (p. 108) and is widespread although many of the localities are of little economic importance. The massive type—pitchblende—is mined in Colorado, the Great Bear Lake region of Canada as well as in Saxony (Germany), Bohemia (Czechoslovakia) and in other parts of the world.

Uraninite has a conchodial to uneven fracture, a hardness of from 3 to 6 and is brown to black in color with a dark green, brown or black streak.

CARNOTITE

This is a complex uranium mineral that is believed to have formed by the weathering and redeposition of other uranium minerals. It is yellow in color, non-crystalline, and may be looked for in deposits of sandstone or conglomerate; it is occasionally found as a replacement of fossil wood.

It occurs in Colorado, Arizona, Utah and at one locality in

Pennsylvania (Mauch Chunk). It is an important source of uranium both in the United States and in the Belgian Congo.

SULFUR MINERALS

Sulfur is primarily used for the manufacture of sulfuric acid which in turn is used in the steel and petroleum industries, the manufacture of explosives, paints, vulcanized rubber, fertilizers and many other products.

In the United States the bulk of the supply comes from pure sulfur deposits, especially in Texas and Louisiana. Pyrite, or iron sulfide, also yields sulfur. Although the United States holds about 80 per cent of the world's supply of pure sulfur, deposits of pyrite are distributed rather widely, the largest reserves being in Spain, Japan, Russia and the United States.

SULFUR

Although crystals are common, sulfur may also occur in a granular, earthy or stalactitic forms. It is usually yellow in color with a white or yellowish streak. Its hardness is 2.

Sulfur is frequently associated with volcanic activity and it is now being quarried from craters of certain extinct or dormant volcanoes. It may also be formed by the alteration of gypsum (calcium sulfate) and such a process is thought to have produced the vast deposits of the Gulf Coast of the United States as well as those in Sicily, the most important sulfur locality of Europe.

In Texas and Louisiana, sulfur occurs as the cap rock of salt domes. In some places it is near the surface and is mined by ordinary methods, while elsewhere it is at considerable depth and is obtained by pumping hot water and compressed air into the ground; the sulfur is thereby melted and forced to the surface where it is allowed to solidify.

Sulfur is a poor conductor of heat and electricity. If a cold

crystal is held in the palm of the hand the resulting temperature change may cause it to expand at the surface and to crack. Therefore, care should be taken in handling museum specimens of sulfur crystals.

PYRITE

Pyrite or iron sulfide is one of the most common of minerals. It is popularly known as "Fool's Gold" because of the apparent resemblance of pyrite crystals to gold. It is, however, harder and more brittle than gold and loses its luster quickly especially in a moist atmosphere. Another popular name for this mineral is iron pyrite.

Pyrite has a hardness of 6 to 6.5, no cleavage and a conchoidal fracture.

Pyrite is found in rocks of all ages and of many sorts. It may occur in veins or ores, or as concretions in rocks of sedimentary origin. It is also commonly associated with coal or lignite.

Pyrite can easily be confused with marcasite, another mineral with the same formula. Marcasite is a little lighter in color than pyrite and is more readily soluble in dilute nitric acid. The two minerals frequently occur together.

If one collects pyrite and places it in a cloth collecting bag, he may find the bag eaten away by sulfuric acid formed by the decomposition of the mineral unless he removes the specimens fairly promptly. In this same way beautiful specimens of pyritized wood may lose their beauty in a relatively short time when exposed to the atmosphere.

PHOSPHORUS MINERALS

Soluble phosphates are required for plant life. These are obtained from material known as *phosphate rock,* which in reality is an impure variety of the mineral apatite. By treating the ground natural rock with an equal weight of sulfuric

acid, a superphosphate is formed which is easily assimilated by plants.

Deposits of phosphate rock are abundant in certain sedimentary formations in Florida, South Carolina, Tennessee, Idaho, Wyoming and Utah. This rock is thought to have been largely formed from the bones and other remains of ancient animals. Bones, teeth, and other fossils are especially abundant in the phosphate beds of Florida, which are largely of Pliocene and Miocene age.

Phosphate fertilizer can also be made from crystalline deposits of apatite.

APATITE

Crystalline apatite is found primarily in rocks of igneous or metamorphic origin.

The mineral may be colorless or brown, green, violet, blue or yellow. It is brittle, transparent to translucent, and has a hardness of 5.

CALCIUM MINERALS

Calcium is exceedingly abundant in nature. It is present in most animals being the essential base in corals, shells and bones. Limestone which is one of the most common of the sedimentary rocks is made up of calcium carbonate. This rock and its variations including cement rock and chalk are of considerable economic importance in many parts of the world.

Calcium is present in many minerals, but only three will be discussed here—calcite, dolomite and gypsum.

CALCITE

Calcite is calcium carbonite and is present in many different kinds of rocks. It frequently occurs as crystals in veins in igneous and sedimentary rocks and in the vicinity of springs. It is also the chief constituent of limestone and marble and in

such rocks is in a massive or finely granular form. It also occurs in hot springs and cave deposits as stalactites, stalagmites, travertine, and onyx (see pp. 101-2).

Calcite is usually colorless or white, but it may be stained pink or some other color. It has perfect cleavage, a conchoidal fracture and a hardness of 3. Calcite is variable in aspect but may be easily identified by dropping dilute cold hydrochloric acid on it which will cause the mineral to fizz as it dissolves. A few other minerals show this same reaction with the acid, but none have the same hardness and cleavage.

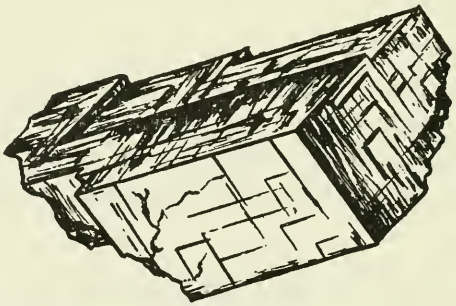


FIG. 71. Crystals of calcite.

The uses of calcite along with limestone and marble are very numerous. Among the most important are for building stone, optical instruments (Iceland spar), quicklime, fertilizer, cement and chalk.

DOLOMITE

This mineral forms the rock of the same name (p. 103). It is a calcium-magnesium carbonate and there are various intergrades between it and pure limestone or calcium carbonate. Dolomite crystals are smaller and less common than those of calcite. Dolomite is white or pinkish, somewhat harder than calcite (3.5 to 4) and only reacts to acid when this is heated.

Dolomite is used for building stone, statues, as refractory material in the steel industry, and as a source of magnesium for various purposes. A rather unusual use of dolomite is made by a plant at Cape May Point, New Jersey. Dolomite (shipped from Pennsylvania) is treated with sea water to produce sintered magnesia for the steel industry.

Dolomite is named for the early French geologist, Dolomieu. The mountains, known as the Dolomites in the Alps, are made up largely of this rock.

GYPSUM

Gypsum is a calcium sulfate and commonly occurs in limestones and shales, or in association with salt deposits. Crystals are common and may occur up to several inches in length. The mineral is usually colorless, shows a prominent cleavage and has a hardness of 2, capable of being scratched by the fingernail.

Gypsum is mined commercially in western New York, Michigan, Iowa, Texas, and California and occurs less abundantly in many other places. It is also found in New Brunswick and Nova Scotia in Canada.

Gypsum is used in the manufacture of plaster of Paris and for certain fertilizers.

MISCELLANEOUS NON-METALLIC MINERALS

MICA

Mica is a general term for a number of related complex silicate minerals of which the best known are *muscovite* and *biotite*. All varieties of mica have highly perfect cleavage; crystals are uncommon, although may occasionally be several feet in diameter. Hardness is between 2 and 3.

Muscovite, the most common variety, is yellowish or brown, transparent or transluscent with a pearly or vitreous luster.

Biotite is generally dark brown or black in color with a white to greenish streak and transparent to opaque.

Muscovite occurs in igneous and metamorphic rocks and, as small fragments, in many sedimentaries. Sheet mica, where the mica occurs in large sheets or "books," is important for use in the manufacture of radio condensers and other electric apparatus. It was formerly used extensively for windows in certain kinds of stoves where it was known as "eisen glass." Biotite has little or no use.

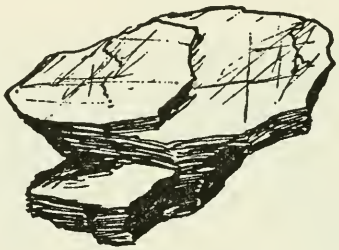


FIG. 72. Mica.

Although the world's greatest source of commercial mica is India, there are important deposits in North Carolina, Georgia, New Hampshire, South Dakota and Quebec.

FELDSPAR

This is a general term for a series of related minerals, which as a group are the most abundant of all minerals. They are generally light in color and are characterized by two good cleavages. The hardness is between 6 and 6.5.

The feldspars make up approximately 60 per cent of igneous rocks and readily weather to kaolin or clay (p. 140). Certain feldspars are of economic importance and are used in the ceramic industry, as abrasives, in the manufacture of porcelain and china, false teeth and for many other purposes. Some

varieties are used as gems, the moonstone being the best-known example (albite).

The most familiar varieties of feldspar are orthoclase, microcline, and plagioclase, which comprises albite, oligoclase, labradorite, and anorthite.

QUARTZ

This is the most common single mineral, and is surpassed in abundance only by the feldspar group of related minerals. Quartz is silicon dioxide and is present in rocks of igneous, metamorphic and sedimentary origin. Crystals are common; it has indistinct cleavage, a conchoidal fracture and a hardness of 7. Many varieties are known including the following:

Rock Crystal Colorless; crystals common; in veins.

Amethyst Purple or violet.

Rose Quartz Pink or rose; usually massive rather than crystalline.

Smoky Quartz Yellow to dark brown.

Milky Quartz Milk-white in color, translucent to opaque.

Flint Cryptocrystalline, in other words the crystals are visible only under the microscope; gray or black, usually in nodules.

Chert Similar to flint, but lighter in color.

Jasper Similar to flint and chert, but usually red or red-brown.

Chelcedony Cryptocrystalline, transparent to translucent with a waxy luster.

Agate Banded variety of chalcedony of chert; used for ornaments or jewelry.

HALITE

This is the substance which constitutes common table salt. It is generally derived from dried lake beds or from ancient arms of the sea where the water has evaporated. Salt is obtained by ordinary mining, or by pumping water down deep wells to dissolve the solid mineral and then recovering the brine. Salt is mined commercially in New York, Michigan, Louisiana, Kansas, New Mexico, Ontario, and elsewhere.

During Colonial days in the United States, salt was obtained by the evaporation of sea water cut off from the open ocean by artificial barriers. This same method is still used today in certain of the islands of the West Indies as well as along the Red Sea in Eritrea and French Somaliland and in other parts of the world.

Halite frequently occurs in crystals, is usually colorless, has perfect cubic cleavage and hardness of 2.5. It is easily identified by its taste.

FIG. 73. Quartz crystals.

Good crystals can be seen on the shore of evaporating or dried-up lakes such as Great Salt Lake and in Death Valley, California.

Salt deposits usually consist mainly of halite or sodium chloride, but may contain other salts such as gypsum.

Although salt is usually associated with sedimentary formations, it may also accumulate as the result of sublimation or concentration from gas vents or craters in volcanic regions.

GRAPHITE

Although graphite and diamond are the same chemically, that is, pure carbon, they have very different physical prop-

erties. Graphite is soft with a hardness of between 1 and 2, while diamond is the hardest of all minerals. Graphite generally occurs as flaky masses or in veins in metamorphic rocks. Some was probably formed by the metamorphism of plant material as in the graphite-coal deposits of Rhode Island; other graphite was probably formed by crystallization from ancient magmas.

The crystals are black in color with a black streak.

Graphite is used in the manufacture of crucibles, paints, and "lead" pencils. Alabama, Texas (and formerly Pennsylvania) are the domestic sources, while the chief foreign producers are Mexico, Korea, Ceylon and Madagascar, Germany, Austria and Czechoslovakia.

SERPENTINE MINERALS

SERPENTINE

This is a secondary mineral formed by the metamorphism of certain ultra-basic igneous rocks. The name serpentine is used for both the rock (p. 118) and one of the characteristic minerals making up that rock. Serpentine is usually green in color, greasy with a conchoidal or splintery fracture and a hardness of a little less than 3. It is a complex hydrous magnesium silicate.

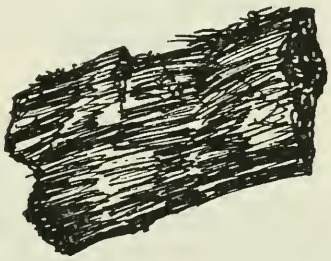


FIG. 74. Asbestos.

The rock serpentine occurs in several varieties, one of which is commonly known as asbestos. This consists of delicate fine parallel fibers which can be separated easily. The fibers are flexible and can be woven into the asbestos cloth of commerce.

Serpentine occurs in many places, but the asbestos variety is most extensively quarried at Thetford Mines, Quebec. It is used in the manufacture of noncombustible materials such as cloth, boards, theater curtains and the like. Massive serpentine is sometimes polished for gems (precious serpentine). For further uses of this material see under the discussion of the rock serpentine (p. 118).

TALC

Like serpentine this mineral is thought to be of secondary origin, having formed as an alteration product. Talc is usually found in metamorphic rocks such as schists and serpentine. Chemically this mineral is closely related to serpentine.

The crystals are tabular or scaly. The mineral has perfect cleavage, an uneven fracture and an average hardness of 1. It it characterized by its greasy or soapy feel giving rise to the popular name *soapstone.*

Talc or soapstone is cut into slabs and used for mantles, wash tubs, table tops, etc. Ground talc is used for talcum powder and some face powders.

The most important talc quarries in the United States are in St. Lawrence County, New York, with other significant localities in New Hampshire, Vermont, Pennsylvannia, New Jersey and Virginia.

GEM MINERALS

DIAMOND

Diamonds are too well known to warrant lengthy description. Colorless diamonds are pure carbon. At the present time Africa furnishes over 95 per cent of the world's diamonds, most

of them from the Union of South Africa, the Belgian Congo and Angola. In South Africa diamonds are associated with a basic volcanic rock known as kimberlite which forms rounded plugs known as "pipes." A pipe similar to those in South Africa occurs near Murfreesboro, Arkansas, and has yielded a moderate number of diamonds, some of gem quality.

A few diamonds have been found in Wisconsin, Georgia, Indiana, Michigan and California. These occur loose and not associated with any igneous pipe. They were probably carried from an unknown source, possibly partly by glacial action.

In addition to the use of transparent crystals as gems, diamonds of less than gem quality are of value for drilling (diamond drilling) and abrasives. Only about 20 per cent of diamonds mined are used as gems.

BERYL

There are several varieties of beryl including the emerald and the aquamarine. They occur in veins of pegmatite as well as in gneiss or a few other kinds of rock. The mineral is a

FIG. 75. Beryl.

complex beryllium aluminum silicate. It has a conchoidal fracture and a hardness of 7.5 to 8. The emerald is green in color and much sought after as a precious stone. The world's best emeralds come from Colombia while others are known from

Russia and Madagascar. The aquamarine is blue to light green in color and is less valuable than the emerald. Brazil has yielded the best specimens of this variety including some crystals weighing several hundred pounds. The common beryl is usually green or yellowish in color and is more widely distributed than the other two varieties. Some crystals of beryl are of gem quality, while others are the source of the metal beryllium which is used, among other things, for atomic energy research. Common beryl is known from New Hampshire, Maine, North Carolina, South Dakota and elsewhere in the United States. The greatest commercial sources are in Brazil.

GARNET

Garnets are complex iron, calcium or magnesium silicates, usually red or red-brown in color, with a vitreous luster, no cleavage and a conchoidal fracture. They are present in igneous and especially metamorphic rocks. Broken from these by weathering, they form the reddish sands of certain beaches, for example those along the coast of New England.

Fig. 76. Garnet.

Some garnets are of gem quality and are prized as jewels; others are used as abrasives.

TOURMALINE

This is a very complex silicate with a variable formula. Tourmaline is a characteristic mineral associated with intrusions of granite. It is usually black in color, although numerous color varieties are also known. It has a vitreous to resinous

luster and a hardness of 7 to 7.5. It readily alters to mica or chlorite.

FIG. 77. Tourmaline.

Tourmalines of suitable color and perfection are used for gems, while varieties not of gem quality are used in the manufacture of short-wave radio transmitters. The mineral is widespread, some of the best American examples coming from Maine, New York and California.

ZIRCON

This is a silicate of the metal zirconium. The mineral is an important gem stone and has been known since ancient times. It is usually brown in color, although varieties of red, blue and yellow are occasionally found. The best gem crystals come from Ceylon, Indo-China and Madagascar, while some very nice specimens have been obtained from Canada. Very minute crystals can be seen in beach sand from New Jersey, North Carolina, Florida and elsewhere.

FIG. 78. Zircon.

Conclusion

WE HAVE LEARNED something about the earth, its main parts, the atmosphere, hydrosphere and lithosphere, as well as the rocks, fossils and minerals that make up its surface. It is the hope of the writer that the reader will not be content with what he has just read. Perhaps the book has answered a few questions, but undoubtedly many questions remain unanswered, and new ones have presented themselves. Many books are available that can give further information on the various branches of Earth Science. A few of them are listed in the accompanying bibliography.

It is also suggested that the reader visit a museum of natural history. Perhaps he will say, "I have already visited museums many times." But it is hoped that, after reading this book, a visit to a museum will mean something a little bit more. The exhibits of the fossils and minerals will not be just "specimens in a case," but actually parts of the earth than can be used by the earth scientist to unravel the mysteries of the ancient past. In other words, they are clues for the "earth science detective."

It is also hoped that the reader will go into the field and try to observe our earth a little more closely than formerly. Perhaps he too can become a detective and find specimens or clues that will reveal ancient chapters in the geological history of his own region. For example, the finding of fossils at the top of a mountain would be dramatic evidence that the sea once covered that region.

This book has not been intended for the future geologist or earth scientist alone. It is true that those readers who plan eventually to make a special study of Geology will probably find information that will be useful in their studies. However, it is hoped that the future business executive, engineer, artist, reporter, or in fact anyone who plans to live on this earth, will benefit by learning something about the planet on which he lives, especially the rocks, fossils and minerals that can be found on its surface.

If one takes a trip, whether it be for geological research, business or pleasure, the trip should mean a little more if the traveler knows something about the rocks that make up the mountains and other features of the landscape. It is not necessary to know the detailed composition and age of the various rocks, but a very elementary knowledge of some of the principles of Earth Science will do much to make the trip more enjoyable.

Another point that we have tried to stress in this book is the great length of geologic time. More than one tourist to the Grand Canyon of the Colorado River has suggested that this great gorge might have been formed by a sudden convulsion of the earth, whereas a little knowledge of geology makes clear that this canyon was formed over a period of millions of years by a very slow process of erosion. In a similar way many of the other scenic features of our landscape were formed slowly during the lapse of thousands or millions of years of geologic time rather than by sudden catastrophes or convulsions. Of course, there are certain exceptions such as those features of the landscape formed by volcanoes or earthquakes of recent times or of the more distant geologic past.

In these days of almost continual crises and the imminent danger that the earth may be blown to bits by super-hydrogen bombs, or that life may be exterminated by radioactivity or some other ghastly phenomenon, it is helpful to contemplate

the long history of the earth and to realize that there have been other crises and that conditions have not been constant. The seas have covered great portions of the present continents, while mountains have been uplifted and leveled to plains. Animals such as the trilobites and dinosaurs have appeared, reached a peak of development, only to become extinct. All this has happened in the geologic past, and while we cannot prophesy the future in detail, we can be sure that great changes are again in store for the earth. New mountains rise, and portions of the present continents will be covered by the sea — as even now is happening along some of our seashores.

What will be the future of Man and the other animals that live on the earth today? Will they also become extinct like the trilobites and the dinosaurs? Or, will Man, because of his superior intelligence, be able to solve some of the problems of evolution, and thus survive where others have failed? No one knows the answers to these questions. To the earth scientist the problems of today make up only a very brief chapter in the story of the earth, placed somewhere between the chapters dealing with the riddles of the geologic past and those concerned with speculations for the future.

Suggestions for Further Reading

ANDREWS, HENRY N. *Ancient Plants and the World they Live in.* Ithaca, N.Y.: Comstock Publishing Co., Inc., 1947.

A readable account of fossil plants.

AUGUSTA, JOSEPH, and BURIAN, ZDENEK *Prehistoric Animals.* Prague, Czechoslovakia: Artia, 1956. (Translated into English by Dr. Greta Horn.)

A beautifully illustrated series of restorations of fossil animals and plants with accompanying text.

COLBERT, E. H. *The Dinosaur Book.* New York: McGraw-Hill Book Co., Inc., 1951.

A well-illustrated book covering dinosaurs and other fossil reptiles. Suitable for the specialist or the layman.

———. *Evolution of the Vertebrates.* New York: John Wiley & Sons, Inc., 1955.

A good summary of vertebrate paleontology suitable for the slightly advanced reader.

DUNBAR, CARL — *Historical Geology*. John Wiley & Sons., Inc., New York: 1949.
One of several fine text books; excellent for reference.

FENTON, C. L. and FENTON, M. A. — *The Rock Book*. New York: Doubleday & Co., Inc., 1940.
A thorough and well-illustrated book, especially suitable for the teen-ager.

———. — *Rocks and their Stories*. New York: Doubleday & Co., Inc., New York, 1951.
An abbreviated version of the above.

FENTON, C. L. — *Prehistoric World*. New York: John Day Co., Inc., 1954.
Frequently used as a reference or supplementary reading in Junior High School.

———. — *The Fossil Book*. New York: Doubleday & Co., Inc., 1958.
A new, well-illustrated book on fossils.

GOLDRING, WINIFRED — *Handbook of Paleontology for Beginners and Amateurs: Part I Fossils*. Handbook 9. Albany, N.Y.: New York State Museum, 1950.

KRAUS, E.H. HUNT, W. F. and RAMSDELL, L. S. — *Mineralogy*. New York: McGraw-Hill Book Co., Inc., 1936.
An advanced textbook, excellent for reference.

LIFE and BARNETT, LINCOLN — *The World We Live In*. New York: Time, Inc., 1955.
Well-illustrated, popular, and reasonably authentic.

MOORE, RAYMOND, LALLICKER, CECIL G. and FISCHER, ALFRED G. *Invertebrate Fossils.* New York: McGraw-Hill Book Co., Inc., 1952.

A college textbook of Paleontology; excellent for reference.

PEARL, RICHARD M. *Mineral Collector's Handbook.* Colorado Springs, Colorado: Mineral Book Co., 1947.

How to collect and know the minerals.

———. *Popular Gemology.* New York: John Wiley & Sons, Inc., 1948.

A popular, but scientific, discussion of gems with good illustrations.

———. *How to Know the Minerals and Rocks.* New York: McGraw-Hill Book Co., Inc., reprinted by New American Library, New York (paper cover), 1957.

An excellent reference for the beginner.

POUGH, FREDERICK *A Field Guide to Rocks and Minerals.* Boston: Houghton Mifflin Co., 1956.

Somewhat more advanced than the above covering many more minerals; color plates.

RICHARDS, HORACE G. *Animals of the Seashore.* Boston: Bruce Humphries, Inc., 1938.

An illustrated guide to the living marine invertebrates of the Atlantic Coast of North America between Cape Cod and Cape Hatteras.

———. *Records of the Rocks.* New York: The Ronald Press Co., 1953.
The geological history of eastern North America.

SHIMER, H. W. and SHROCK, R. R. *Index Fossils of North America.* New York: John Wiley & Sons, Inc., 1944.
Brief descriptions and figures of all important genera of invertebrate fossils. A "must" for all paleontologists.

SHROCK, R. R. and TWENHOFEL, WILLIAM *Principles of Invertebrate Paleontology.* New York: McGraw-Hill Book Co., Inc., 1953.
A college textbook, also valuable as a reference.

SWENSON, VALERIE *A Child's Book of Stones and Minerals.* New York: Maxton Publishers, Inc., 1955.
For the very young beginner.

VAN ROYEN, WILLIAM and BOWLES, OLIVER *The Mineral Resources of the World.* New York: Prentice-Hall, Inc., 1952.
Contains considerable information on the world distribution of important mineral resources.

ZIM, HERBERT, SHAFER, PAUL and PERLMAN, RAYMOND *Rocks and Minerals.* New York: Simon and Schuster, Inc., 1957.
A well-illustrated summary of the subject for the beginner or amateur; paper cover.

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